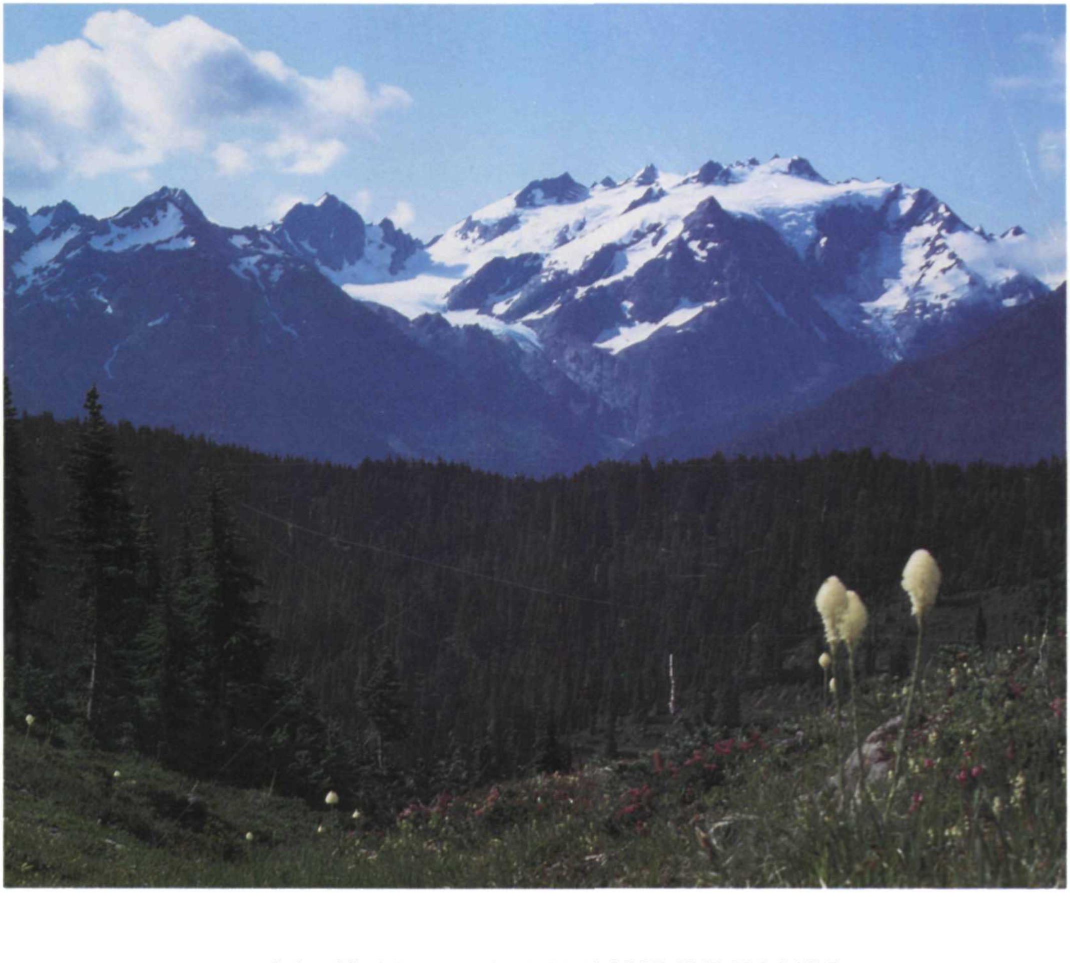
Mountain Goats in Olympic National Park: Biology and Management of an Introduced Species



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Douglas B. Houston

Edward G. Schreiner

Bruce B. Moorhead

National Park Service
Olympic National Park
600 E. Park Avenue
Port Angeles, Washington 98362

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Contributors

Nelsa M. Buckingham Botanist, 1127 W. 7th, Port Angeles, Washington 98362.

Janis E. Burger Biological Technician and Interpretive Specialist, Olympic National Park, 600 E. Park Ave., Port Angeles, Washington 98362.

Michael B. Gracz Biological Technician, formerly Olympic National Park.

Roger A. Hoffman Natural Resource Specialist, Olympic National Park, 600 E. Park Ave., Port Angeles, Washington 98362.

Douglas B. Houston Research Biologist, National Park Service, Pacific Northwest Region, 83 S. King St., Seattle, Washington 98104 (Duty station, Olympic National Park).

Thomas N. Kaye Biological Technician, formerly Olympic National Park. Current address: Oregon Department of Natural Resources, Salem, Oregon 97310.

Bruce B. Moorhead Management Biologist, Olympic National Park, 600 E. Park Ave., Port Angeles, Washington 98362.

Richard W. Olson Park Ranger, Olympic National Park, 600 E. Park Ave., Port Angeles, Washington 98362.

Edward G. Schreiner Research Biologist, National Park Service, Pacific Northwest Region, 83 S. King St., Seattle, Washington 98104 (Duty station, Olympic National Park).

Susan Schultz Historian, Olympic National Park, 600 E. Park Ave., Port Angeles, Washington 98362.

Victoria Stevens Research Biologist, 1525 Fell Street, Victoria, British Columbia, Canada V8R 4V9.

Andrea Woodward Research Biologist, National Park Service, College of Forest Resources, University of Washington, Seattle, Washington 98195.

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Mountain Goats in Olympic National Park: Biology and Management of an Introduced Species

Douglas B. Houston

Edward G. Schreiner

Bruce B. Moorhead

Abstract. Mountain goats (*Oreamnos americanus*), introduced to the Olympic Mountains during the 1920's, are regarded now by the National Park Service as unwelcome additions to the unique biota of Olympic National Park (3,700 km^2). We report results of studies of mountain goat biology and of management activities conducted in 1981–92. Thirty-five endemic forms of plants and animals are currently recognized on the Olympic Peninsula. The native mammalian fauna and the coniferous flora are impoverished compared to the nearby Cascade Mountains (12 fewer mammals, 5 fewer conifers). Goats colonized the Olympic Mountains in about 60 years. The goat population consisted of quasi-independent subpopulations that grew and declined asynchronously. The metapopulation was estimated by helicopter census to be 1,175 ± 171 (SE) goats in 1983 and 389 ± 106 in 1990; National Park Service removals contributed to the population decline. Mountain goats were removed from the Klahhane Ridge subpopulation to examine changes in demography and physical condition. Initial breeding age declined, litter size increased, and production and recruitment of kids were less variable at lowered goat densities. Changes in demography were associated with increases in live weights and fat reserves. Marked differences in reproductive performance occurred among females. Mountain goats were seasonally migratory and occupied subalpine and alpine areas above 1,520 m during summer. Goats were closely associated with rocks and cliffs at all seasons and ate a wide variety of foods, including four endemic plant taxa. Group size averaged less than three goats during summer and winter. Eighty-four percent of 125 goats tagged on Klahhane Ridge showed fidelity to summer ranges, some for 5–10 years. Interspecific competition for resources between mountain goats and the native fauna could not be demonstrated from the scant data available. Our work demonstrated that introduced mountain goats changed the vegetation of the Olympic Mountains, a finding held in common with all other studies of ungulate grazing systems. Six hundred ninety-nine plots showed that goat herbivory was distributed throughout the park above 1,520 m. Permanent vegetation plots on summer ranges showed that mountain goat herbivory changed the composition of subalpine meadows; disturbance-oriented species (e.g., *Achillea millefolium*) increased and selected forage species declined (e.g., *Festuca idahoensis*). The cover of selected forage species was negatively correlated with mountain goat density at sites with initially high levels of goat herbivory. Sixty-six photographic comparisons from Klahhane Ridge also showed that cover of disturbance-oriented species and the amount of exposed mineral soil were related to goat densities. Mountain goat summer range and the habitat of 33 rare plant taxa—including 7 peninsula endemics—overlapped considerably. Mountain goats affected and killed individual rare plants by grazing, wallowing, and trampling, but our preliminary studies could not determine trends in rare plant populations subjected to goat herbivory. Circumstantial evidence suggested that goat herbivory may have reduced densities of the rare endemic *Astragalus australis* var. *olympicus* on Mount Angeles compared to Blue Mountain. Effects of goats on *Astragalus* were sporadic—sometimes intense—and had unknown long-term consequences to the survival of the species. Goat management in the park during the 1980's occurred as an experimental management program (1981–87) and as operational management (1988–89). About 693 mountain goats were captured from 1977 to 1989, and personnel gained considerable experience with different capture and removal techniques. During 1981–89, 407 goats were removed from the park. The operational management program was terminated in 1989, when continued goat capture posed unacceptable risks to the capture team. Field sterilizations were attempted on 19 goats (13 females, 6 males) to evaluate this control technique. The cost and effort required to implement four strategic management options in the future (ranging from elimination to allowing the entire mountain goat population to achieve ecological carrying capacity) were explored using population models. All control or elimination options will be difficult and expensive to achieve in practice. Tactical options available for elimination or intense control of goats are limited to shooting and aerial live capture; currently available sterilization techniques could, at best, partially control the population.

Key words: Biogeography, demography, exotic species, grazing, herbivory, management, mountain goat, national park management, Olympic National Park, Olympic Peninsula, *Oreamnos americanus*, population estimates, rare plants.

Chapter 1. Introduction

D. B. Houston and E. G. Schreiner

The spectacularly rugged Olympic Mountains dominate the landscape of Washington's Olympic Peninsula. Geographic isolation has led to a mammalian fauna that is markedly less diverse than that of the nearby Cascade Mountains and to endemism among native plants and animals. Mountain goats (*Oreamnos americanus*), introduced into the Olympic Mountains during the late 1920's, have colonized virtually the entire range. Olympic National Park was established in 1938 as a 3,700-km^2 natural area to conserve the native biota. Goats are now considered by the National Park Service as an unwelcome addition to the fauna.

Mountain goats of Olympic National Park are but one example of the pervasive influence of humans on the earth's biota—greatly accelerating the spread of plants and animals around the globe. Introduced exotic or alien species often disrupt established ecosystem processes and pose management problems for national parks. This is the situation in Olympic National Park: goats have modified the vegetation—as all large herbivores do—and, thereby, have affected endemic plants.

Mountain goats are among the least known of North America's ungulates. National Park Service personnel studied the biology and management of mountain goats in 1981–92. Fieldwork included studies of mountain goat abundance, demography, habitat relations, and the effects of goat herbivory on the park's vegetation. Park management programs, particularly the experimental management program conducted in 1981–85, enabled us to add considerably to our knowledge of the ecology of mountain goats and to test capture and control techniques. Following the experimental program and an analysis of management alternatives (National Park Service 1987), the National Park Service initiated operational management. We report information from the 1981–92 studies, evaluate the effectiveness of the 1988–89 operational program designed and implemented primarily to eliminate mountain goats from the 3,250-km^2 core of the park, and consider goat management options for the future. Our findings increase the knowledge about mountain goats and provide information for biologists that manage these fascinating creatures.

Our intended audience includes the scientific community, the resource managers, and the interested public. Experience in scientific and public forums during the past 15 years has convinced us that the ecological concepts that underlie national park management goals need clear explanation and wider recognition. In this introductory material, we review natural area management—including National Park Service policy on the management of introduced species—to provide information essential to develop an understanding of the mountain goat issue.

Management of National Parks

Mountain Goats in Olympic National Park

The presence of mountain goats is interpreted to be contrary to the stated purpose of Olympic National Park. Congress determined that the purpose of the park was

> ...to preserve, for the benefit, use and enjoyment of the people, the finest sample of primeval forests of Sitka spruce, western hemlock, Douglas fir, and western red cedar in the entire United States; to provide suitable winter range and permanent protection for the herds of native Roosevelt elk and *other wildlife indigenous to the area* [emphasis added]; to conserve and render available to the people, for recreational use, this outstanding mountainous country, containing numerous glaciers and perpetual snow fields, and a portion of the surrounding verdant forests together with a narrow strip along the beautiful Washington coast (75 U.S. Congress 1938).

National Park Service Natural Area Management

The conservation of nature is generally accepted as the primary goal of parks, but biologists and managers have struggled to define ecological objectives for the large natural area parks, such as Yellowstone and Olympic (e.g., Leopold et al. 1963; Houston 1971; Agee and Johnson 1988).[1] A succinct review of worldwide park management goals provides a useful perspective on management alternatives (Shepherd and Caughley 1987:191):

> The management of a national park will be determined by whether the aim is to conserve biological and physical states by suppressing processes or whether it is to preserve processes without worrying too much about the resultant states. Specifically, there are three options: (1) If the aim is to conserve specified animal and plant associations that may be modified or eliminated by wildfire, grazing or predation, then intervene to reduce the intensity of wildfire, grazing or predation. (2) If the aim is to give full rein to the processes of the system and to accept the resultant, often transient, states that those processes produce, then do not intervene. (3) A bit of both—if the aim is to allow the processes of the system to proceed unhindered unless they produce 'unacceptable' states, then intervene only when unacceptable outcomes appear likely.

---

[1] The National Park Service manages a bewildering array of 361 units. These range from historical monuments to recreation areas and national seashores to the large natural-area parks. Enabling legislation, congressional intent, and consequent management objectives differ among units. Our concern here centers on the natural-area parks.

Option 3, with strong emphasis on allowing processes to approach full rein, best describes our perception of the management goals for large United States parks.

Serious questions remain about our ability to meet biological goals in the future. Ecosystems leak. Consequently, a truly self-contained natural area will remain an ideal that cannot be fully achieved; compensatory management may lie in the future for most United States parks, but the level of human intervention required is still unclear. Parks are beset with problems that include the difficulties of fully restoring forces (e.g., fire) that drive ecological processes, the possibility that areas may be too small to maintain viable populations of native species over time (Newmark 1987), and the alteration of ecological processes by the introduction of alien species.

Alien Species in Parks

Biogeography teaches that distributions of plant and animal species change continually through time. The natural distributions of North American species have changed considerably since the waning of the Wisconsin glaciation, a mere 18,000–15,000 B.P. (Pielou 1991).[2] Mammal distribution, for example, has changed markedly during just the past 10,000 years, with major shifts of terrestrial species continuing into mid-Holocene times (Graham and Mead 1987; Pielou 1991). The degree to which these shifts in distribution must be considered in designating species status in parks is considered below.

Humans have accelerated the spread of species around the earth. The long-term ecological consequences of these activities are not fully understood (e.g., Elton 1958), but the magnitude of the management problems posed to United States national parks by the introduction of exotic or alien organisms is considerable. In a 1980 report to the Congress, 300 National Park Service areas reported 602 perceived threats to natural resources involving alien plants and animals (National Park Service 1980a).

Concern about alien species in parks was expressed in the scientific community as early as the 1920's (Lien 1991) and was reinforced by National Park Service scientists in the 1930's (e.g., Wright et al. 1933). The concern centered on the disruption of established ecosystem processes by introduced species. Policies on the introduction and management of exotic species evolved in concert with the broader biological goals of parks (Cahalane 1948; Leopold et al. 1963; Wright 1992; J. G. Dennis, National Park Service Research on exotic species and the policy behind that research, San Francisco, unpublished report). Leopold et al. (1963:5) were particularly blunt that the biota of national parks should "... be limited to native plants and animals."

Current policy states, "Exotic species are those that occur in a given place as a result of direct or indirect, deliberate or accidental action by humans (not including deliberate reintroductions). ... The exotic species introduced because of such human action would not have evolved with the species native to the place in question and, therefore, would not be a natural component of the ecological system characteristic of that place." Moreover, "Management of populations of exotic plant and animal species, up to and including eradication, will be undertaken wherever such species threaten park resources or public health and when control is prudent and feasible" (National Park Service 1988).

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[2] Dates of events are given as years before present—that is, 10,000 years Before Present is represented as 10,000 B.P.

Interpretation of this general policy is usually straightforward: eastern brook trout (*Salvelinus fontinalis*) in Yellowstone and Olympic parks, feral goats (*Capra hircus*) and eucalyptus trees (*Eucalyptus* spp.) in Maui's Haleakala Park, and European wild boars (*Sus scrofa*) in Great Smoky Mountains Park are exotic beyond reasonable argument (i.e., within a time frame of millennia). However, troublesome areas remain that involve spatial and temporal scales where policy seems to collide with biogeography. We examine six case histories including three involving challenges to National Park Service policy in which the issue was resolved by the courts.

Burros in Grand Canyon National Park

In the 1970's, the National Park Service proposed to eliminate free-ranging burros (*Equus asinus*) from Grand Canyon National Park because the animals were exotic (feral since the 1870's or earlier), altered native plant communities, and possibly competed with native wildlife (National Park Service 1979, 1980b). The proposal was contested on several grounds, but the one of interest here involved several paleontologists who viewed burros as the ecological equivalents of late Pleistocene equids (*E. conversidens*) formerly found in the area. The native equid became extinct about 11,500 B.P., possibly at the hand of early humans (Martin 1970, 1979; Cole 1980). Other scientists and the National Park Service (Carothers et al. 1976, 1979) disagreed with these interpretations because (1) North American equids were related to the North African progenitors of the burro only at the subgeneric level (e.g., Harris and Porter 1980), and (2) late Pleistocene environments no longer occurred in Grand Canyon—that is, plant communities differed, and the array of Pleistocene species associated with the extinct equids (including other large herbivores, predators, parasites, and diseases) were now largely absent. A subsequent legal challenge based in part on the question of the exotic status of the burro failed (Copple 1980; legal papers filed in Civil Case 80-416-PHX-WPC). The court also upheld the validity of the broader National Park Service policy on exotic species management.

Burros in Bandelier National Monument

In a related case, a National Park Service proposal to remove burros from New Mexico's Bandelier National Monument was disputed initially on grounds that the agency failed to follow National Environmental Policy Act (NEPA) requirements. The U.S. District Court found in favor of the National Park Service and accepted as finding of fact that burros were exotic species, as defined by National Park Service policy (Burciaga 1980). This decision was appealed by the American Horse Protection Association; arguments again invoked the occurrence of Pleistocene equids and the derivative notion that burros should be considered native to New Mexico. The U.S. Court of Appeals (1982) did not accept this argument or the others concerning NEPA procedural issues, and the National Park Service prevailed.

Bolson Tortoise in Big Bend National Park

The Bolson tortoise (*Gopherus flavomarginatus*) is an endangered species that occurs in north-central Mexico. Introduction of the tortoise to Big Bend National Park was proposed on grounds that the same or a closely related species occupied the region until late Pleistocene–early Holocene times (G. Aquirre and G. Adest, Repatriation of Bolson tortoises into Big Bend National Park, Instituto de Ecologia, Durango, Mexico, unpublished report). The fossil record suggests that the tortoise has undergone a reduction in body size and a contraction of geographic range since the late Pleistocene. The tortoise has apparently been absent from the Big Bend area for thousands of years and now occupies 6,000 km^2 in Mexico, some 240 km from the park. No assessment has been made of the potential effect of the proposed introduction on the extant flora and fauna of Big Bend. Following detailed review, the National Park Service ruled the tortoise to be an exotic species and therefore inappropriate to introduce into Big Bend, its status as an endangered species notwithstanding (M. Ruggiero, Policy review on proposal to introduce the Bolson tortoise to Big Bend National Park, National Park Service, Washington, D.C., unpublished memo).

Bison in Wrangell–St. Elias National Park

Bison (*Bison bison*) were introduced into Alaska's Copper River (in 1950) and Chitna River valleys (1962)—areas subsequently incorporated into Wrangell–St. Elias National Park and Preserve in 1980 (Peek et al. 1987). Bison evidently persisted in Alaska, at least north of the Alaska Range (ca. 500 km from Wrangell–St. Elias), until about 500 B.P., just before European contact (i.e., their extinction was "natural"). South-central Alaska, including Wrangell–St. Elias, was heavily glaciated during Pleistocene advances, and no post-Pleistocene bison remains are known from the area. Additionally, the introduced animals were plains bison (*B. bison occidentalis*), not the wood bison (*B. bison athabascae*) subspecies currently recognized by some mammalogists (Meagher 1986). [Note: This may now be an irrelevant issue because Geist (1991) considered *B. bison athabascae* to be simply an ecotype, not a valid taxon]. Peek et al. (1987) questioned whether or not bison should be considered exotic and suggested that the National Park Service needed to define the concept of *native species* on temporal and spatial scales. The current Wrangell–St. Elias position is to consider the bison exotic (K. Jenkins, Wrangell–St. Elias National Park, Glennallen, Alaska, personal communication, 1991).

Horses in Ozark National Scenic Riverways

In 1990, the National Park Service proposed to remove feral horses (*Equus caballus*) by live capture from the "natural zones" of the 327-km^2 Ozark National Scenic Riverways. In 1964, the Congress authorized the riverways with an extremely broad enabling statute: "For the purpose of conserving and interpreting unique scenic and other natural values and objects of historic interest...management of wildlife, and provisions of use and enjoyment of the outdoor recreation resources..." (Higgins 1991). Fewer than 30 horses occupy the riverways, and horses have been present since the 1940's. The proposed removal was challenged by local residents on several grounds, including the contention that horses should be considered native species, wildlife, and cultural resources under National Park Service policy.

In June 1992, a U.S. District Court found in favor of the plaintiffs, even though accepting National Park Service arguments that the horses were rightfully classified as exotic species. The court concluded "... that the decision to remove the horses constituted a clear error in judgment as to whether governing statutes and management policies required removal of the horses and the decision failed to consider relevant facts, in particular, the damage caused by removal of the horses and whether the horses are cultural or historical objects" (Limbaugh 1992).

The case was appealed, and in June 1993 the district court decision was reversed. The Court of Appeals found that the earlier decision did not use the proper standard of judicial review of agency decision-making and that there was sufficient evidence that the continued presence of the exotic horses was in conflict with the purpose of the park (U.S. Court of Appeals 1993). Plaintiff's petition for certiorari to the U.S. Supreme Court to examine the appellate court decision was denied, thus the appellate decision stands (W. D. Back, Solicitor, U.S. Department of the Interior, Portland, Oregon, personal communication, 1994).

Mountain Goats at Olympic National Park

Even though early naturalists reported that mountain goats were absent from the Olympic Mountains and that the animals were known to have been introduced in the 1920's, Lyman (1988) challenged the idea that the National Park Service should view the goats as alien species. Lyman's arguments were based on a speculative dispersal model for *Oreamnos* during the late Quaternary. Based on the model, mountain goats might have occupied the Olympic Mountains during the Quaternary. He also speculated that mountain goats may have been present historically in unexplored areas of the mountains (Lyman 1988).

This challenge prompted the National Park Service to review the basic premise of goats as alien species. The ethnographic record indicated that mountain goats did not occur in the Olympic Mountains during the nineteenth century but that an extensive trade network among native peoples brought goat wool (prized for blankets and garments) and horns (for utensils) to the Olympic Peninsula (Schalk 1993). Goat bones have not been identified in remains from 24 archaeofaunal sites on the peninsula (mostly from the last 1,000 years of the prehistoric record). Schalk

(1993) cautioned, however, that because of the temporal range and location of the archaeological sites (mostly coastal areas some distance from the mountains) and the general shifts in mammalian distribution during the late Quaternary, the archaeofaunal data did not permit conclusive statements regarding the presence or absence of goats during the late Pleistocene or Holocene before the nineteenth century.

Schultz (1993 and Appendix B) reviewed historic accounts beginning with the Spanish exploration of the Strait of Juan de Fuca in 1790 and explorations of the mountain range in the late nineteenth century to records from 1925, which was around the time of the goat introductions. Considerably more historical information existed on early conditions in the Olympic Mountains than was reported by Lyman (1988). Schultz noted the difficulties of interpreting negative evidence and the occasional confusion over common names applied casually to wildlife species through the nineteenth century. She concluded that mountain goats were not present historically.

Note that the arguments for possibly considering mountain goats to be native species prehistorically in the Olympic Mountains contain elements of analogous arguments concerning bison at Wrangell–St. Elias and burros at Grand Canyon. The National Park Service continues to view the mountain goats as alien to the Olympic Mountains (National Park Service 1994).

The six case histories raise several philosophical and biological questions for scientists and park managers:

1. Given the dramatic changes in species distribution in North America from the close of the Pleistocene, what temporal and spatial scales of species distribution are appropriate to consider in national parks? Corollaries may include the following: How long does a species have to be extinct, or by what agent, before its reintroduced successors are to be considered alien? Following Peek et al. (1987), is it appropriate for humans to introduce a species that has become extinct from natural causes into an area where the native fauna is to be retained intact?
2. What obligation, if any, do national parks have in conserving a broader regional species diversity—should species in jeopardy elsewhere be introduced to a park simply to provide an added measure of protection?
3. How different must a taxon be before it is judged to be too different from one present earlier—subspecies, species, genus?

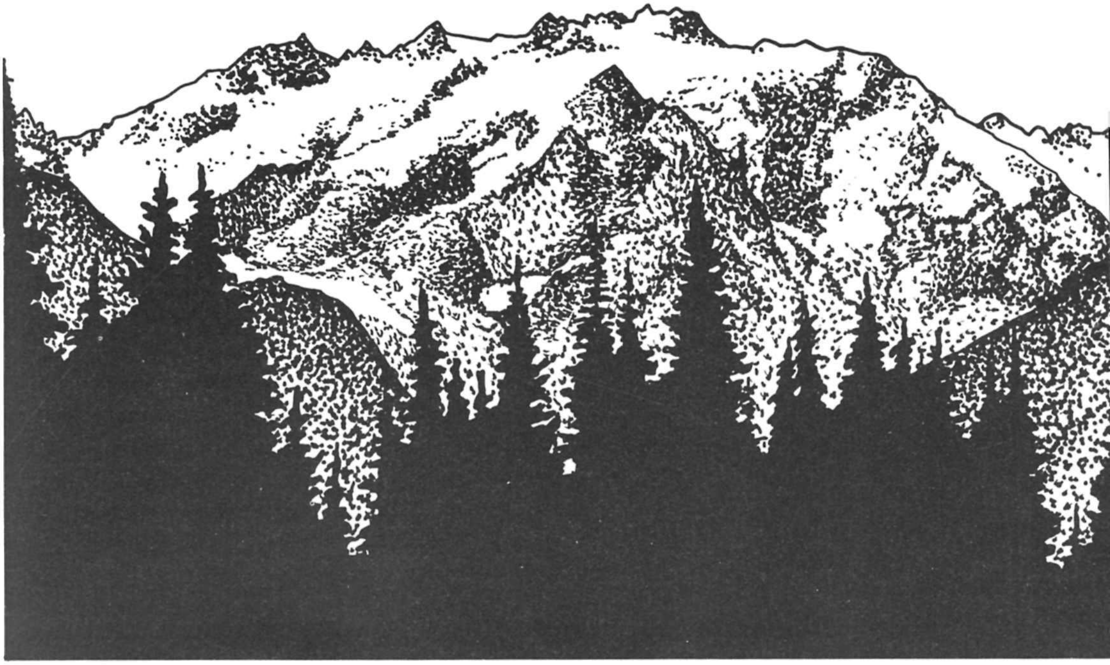
Definitive answers cannot be provided to these questions, but we offer a perspective based on the broader objectives for United States national parks. Granting the dramatic post-Pleistocene changes in species distribution, our understanding is that the national parks were not established to attempt to recreate late Pleistocene or early Holocene biotas. Parks were set aside to conserve the extant biota, in essence to conserve the outcome of the dramatic ecological events of the late Quaternary, including local extinctions, that shaped the existing flora and fauna. Pragmatically, then, the National Park Service is primarily concerned with historic, post-Columbian species distributions, recognizing that these too change naturally over time. This seems at least to be the implicit interpretation of current policy (National Park Service 1991). This view also recognizes that it is entirely appropriate to restore species eliminated directly or indirectly by Euro–Americans.

If this perspective is valid, then a conservative interpretation of the National Park Service policy on exotics seems prudent because of the relative rarity of large natural areas, their value as baselines or controls for other ecosystems exploited by humans (Jenkins and Bedford 1973), and our general ignorance of ecosystem dynamics and processes (i.e., park resources are always managed with an air of uncertainty; Walters 1986). Introducing species adds to uncertainty. Our inability to predict the outcome of interactions of introduced organisms with either the abiotic forces driving ecosystem processes (e.g., fires, climatic change) or the extant biota means that, with too liberal an interpretation of the exotic species policy, we unnecessarily risk considerable alteration of ecological relations.

From this viewpoint, it is irrelevant that an equid occurred in the Grand Canyon or a tortoise occurred at Big Bend during the late Pleistocene or that a form of mountain goat might have occupied the Olympic Mountains at an earlier time. In the park situations described, these species are prudently classed as exotic, a perspective in accord with the few legal decisions rendered.

Mountain goat management at Olympic National Park has been controversial. No matter how the issue is eventually resolved, the decision must be based, in part, on scientific information. We trust that this monograph provides the information necessary.

The Olympic Peninsula



Chapter 2. The Olympic Mountains and Environs

D. B. Houston and E. G. Schreiner

The Olympic Mountains rise sharply from the surrounding coastal plain and foothills to dominate the 13,800-km^2 Olympic Peninsula. The peninsula is bounded on the west by the Pacific Ocean, the north by the Strait of Juan de Fuca, and the east by the Hood Canal extension of Puget Sound (Fig. 1). The southern boundary of the Olympic Physiographic Province is arbitrary but is customarily drawn through the Chehalis River lowlands to Grays Harbor, a demarcation of earlier glacial outflow channels that drained the Puget lobe of the Cordilleran ice sheet. Adjacent lowlands to the east, including the Kitsap Peninsula, are usually considered part of the Puget Trough Province (Franklin and Dyrness 1988).

Mount Olympus is the highest peak at 2,430 m, and 37 other major peaks exceed 2,130 m. About 266 glaciers cover 46 km^2 of the range, with a total ice volume of 1.7 km^3 (Spicer 1986). The largest glaciers, with 78% of the volume, are centered on the Mount Olympus massif. Eleven major rivers radiate from the mountains; Mount Anderson represents the hydrographic apex of the peninsula as water flows from it into the ocean, strait, and sound.

Geology

The complex geologic history of the Olympics has been described by Tabor (1987). The Crescent Formation, composed primarily of Eocene basalts, occurs in a horseshoe shape around the northern, eastern, and southern periphery of the range. The core rocks of the central and western part of the mountains are primarily marine sediments (sandstones, shales, conglomerates) of Eocene to mid-Miocene age (i.e., 20–58 million years old). Core rocks were partially thrust under the older peripheral rocks during subduction of the oceanic plate. Mountain goats occupy terrain composed of core rocks and peripheral rocks of the Crescent Formation.

The Olympic Mountains began uplift during the Miocene epoch (from 26 to 7 million years ago), and the mountain mass may still be rising (Tabor 1987). The radial drainage pattern was established early as water ran off in all directions from the rising domed landmass. The uplifted mountains intercept moisture-laden air from the Pacific Ocean and the high precipitation causes rapid erosion. Subsequent erosion has resulted in precipitous mountain slopes (Fig. 2). Moreover, the range was sculpted repeatedly by glaciers during the last 1.5–2.0 million

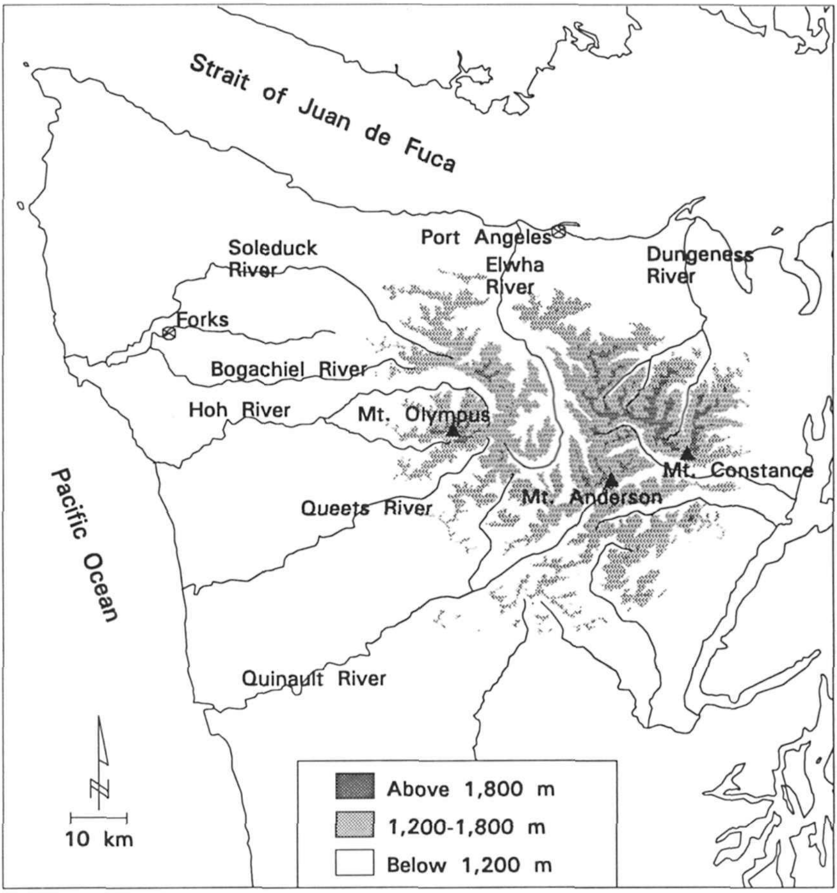


Fig. 1. The Olympic Peninsula, showing major river drainages, mountain peaks, and zones of elevation.

years of the Pleistocene epoch. Recent studies suggest that massive prehistoric earthquakes also affected the landscapes of western Washington: quake-induced rock avalanches blocked streams and formed lakes in the eastern Olympics during the past 1,300 years (Schuster et al. 1992).

Glacial History

Studies of oxygen isotopes in fossils from marine sediments suggest that more than 20 ice ages occurred during the Pleistocene (Mix 1987), although

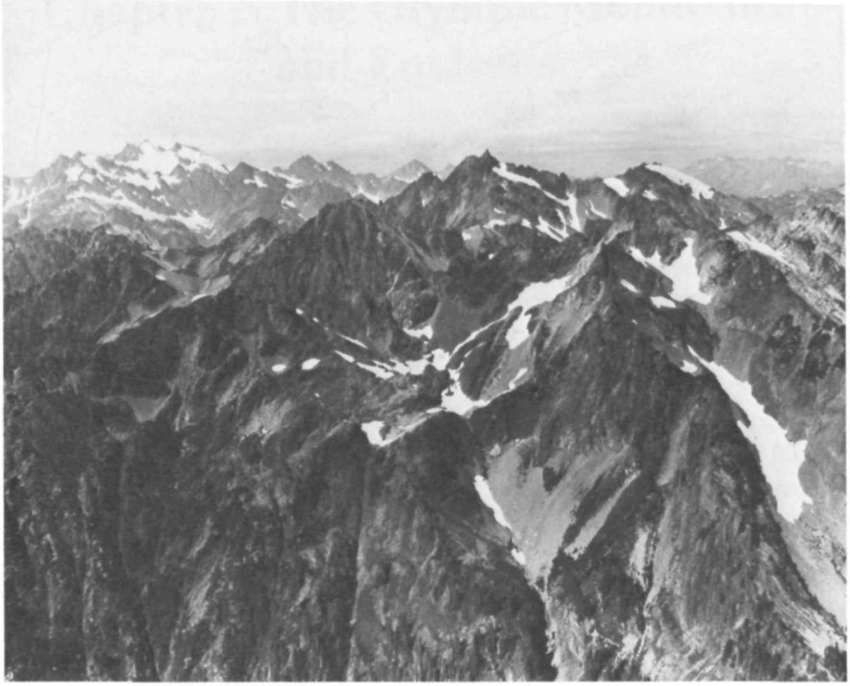


Fig. 2. South slopes of Mount Seattle, view northwest to Mount Olympus showing the rugged character of the Olympic Range. (Photo by L. Kirk, 1961; National Park Service files)

the number that actually affected the Olympics is unknown. However, the most recent Wisconsin ice age is comparatively well-chronicled and involved several glaciations between about 100,000 and 10,000 B.P. At least six left records in the Puget Sound area, with the last—the Fraser glaciation—being the best documented. The following interpretation of glacial history was drawn primarily from Porter et al. (1983), Waitt and Thorson (1983), Ryder and Thomson (1986), Booth (1987), Tabor (1987), Henderson et al. (1989), and Pielou (1991).

The Fraser glaciation lasted about 10,000 years and consisted of 3 stades (periods of ice expansion) and 2 interstades (ice recession). The Fraser ice advance in the Olympics began with expansion of alpine glaciers—the Evans Creek stade. Although poorly dated on the Olympic Peninsula, at maximum advance—about 21,000–18,000 B.P. (Porter et al. 1983; Waitt and Thorson 1983)—glaciers extended down west-side valleys (Fig. 3). Glaciers in east-side drainages were smaller and were restricted to upper valley areas or

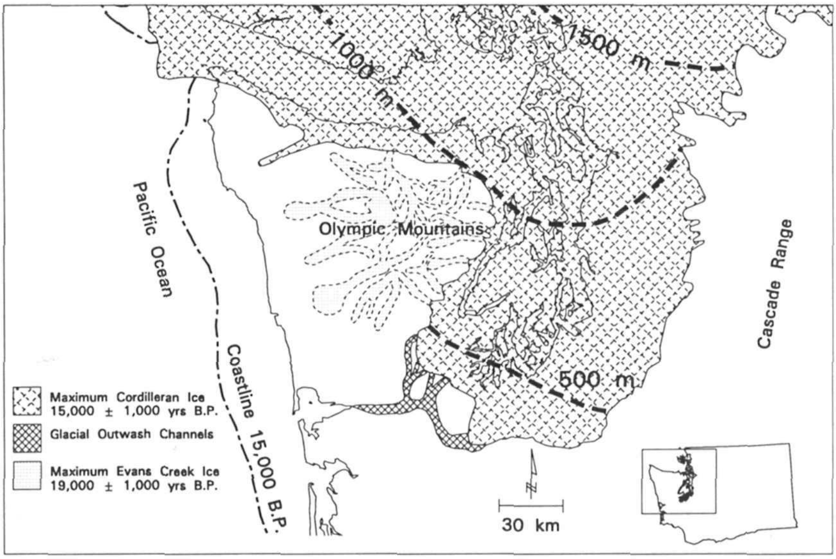


Fig. 3. *The Olympic Peninsula, showing the distribution of glaciers during the* Evans Creek stade and the extent of Cordilleran ice during the Vashon stade. The extent of Evans Creek glaciation is speculative and based on incomplete surveys. Modified from Crandell (1964, 1965), Moore (1965), Carson (1970), Heusser (1974), Waitt and Thorson (1983), and Booth (1987).

headwalls (Long 1975). The Evans Creek advance coincided with the beginnings of an enormous ice buildup in the mountains of British Columbia.

Alpine glaciers retreated to undetermined positions up valleys following the Evans Creek stade (Booth 1987). This brief interstade was followed by advance of the Cordilleran ice sheet from British Columbia into the Puget Sound area—the Vashon stade (Fig. 3). The ice reached its maximum extent around 15,000 B.P., splitting into the Juan de Fuca and Puget ice lobes as it encountered the Olympic Mountains. Ice at the northeast corner of the Olympics was at least 1,050 m thick at maximum advance (Tabor 1987). The Vashon ice produced glacial lakes behind massive ice dams that formed in the northern and northeastern river valleys (to about 600 m in the Elwha). The ice sheet apparently did not contact the remaining alpine glaciers (Booth 1987; Tabor 1987). The spatial and temporal relations between ice sheets and alpine glaciers have important implications for the biogeography of endemic taxa; suitable habitat for alpine plants evidently persisted in or near the Olympic Mountains during both alpine and ice sheet advances of the Fraser glaciation.

The Vashon advance was short-lived; by 13,600 B.P., the two lobes had receded into a single lobe located in the northern Puget lowlands. A minor readvance (the Sumas stade) occurred about 11,500 B.P., but the extent and climatic significance of this stade has been questioned (Booth 1987). The Fraser glaciation ended about 10,000 B.P. when major climatic changes occurred.

The Wisconsin ice age gave way rapidly to a period of maximum postglacial warmth in the early Holocene. The timing of this climatic optimum varied across North America, but the period from 10,000 to 7,000 B.P. was apparently the warmest and driest part of the postglacial time in the Pacific Northwest (Barnosky 1984). The early Holocene warmth next yielded to the Neoglacial period of colder and wetter climates around 5,000–4,000 B.P. Alpine glaciers in western North America formed anew about 5,000 B.P. and subsequently retreated and advanced twice, at about 2,800 and 300 B.P. This last advance (actually a series of local advances and recessions) marks the Little Ice Age (LIA), which occurred from around A.D. 1350 to 1870. In the Olympics, the Blue and Hoh glaciers on Mount Olympus apparently reached their maximum LIA positions during the early decades of the nineteenth century (Heusser 1957; Spicer 1986). The glaciers retreated rapidly during the late nineteenth and early twentieth centuries. The retreat slowed in the 1950's, a minor advance occurred during 1960–80, and the ice fronts have been relatively stationary since. In addition to the recession of alpine glaciers in the late nineteenth century, Henderson et al. (1989) noted that large areas covered by year-round snow only 200 years ago are now open rock, scree, or talus. Abrupt transitions from unweathered rock debris to vegetated areas often mark the extent of the former LIA ice fields.

Climate

The climates of the Wisconsin ice age provide a convenient baseline against which to measure subsequent trends. Mean annual temperatures in the southern Puget Trough around 20,000–16,000 B.P. have been estimated to be 5–7 Celsius degrees colder than today; precipitation was perhaps 100 cm less—about 50 cm annually (Whitlock 1992). The early Holocene temperatures of 9,000 B.P. were perhaps 1–3 Celsius degrees warmer than at present; precipitation was about half that of today, or around 75 cm. Temperatures during the LIA were perhaps 1–2 Celsius degrees colder than present (Lamb 1982).

Annual temperatures have increased nearly 1 Celsius degree in the Northern Hemisphere during the past century at the latitude of the Olympic Peninsula (Hansen and Lebedeff 1987). The increased temperatures are suggested by the records from Port Angeles, but the trend is not pronounced, probably because the station is under considerable maritime influence (Fig. 4). Port Angeles records show reduced annual and seasonal precipitation from about 1920 to 1940. Tree-growth studies confirm this, indicating that these 2 decades represent the most prolonged spring–summer drought in the past 300 years (Brubaker 1980). Shorter-term records show a trend of reduced snow in the Olympic Mountains; pronounced lows in 1 April snow measurements occurred in the 1960's and from the late 1970's to the present.

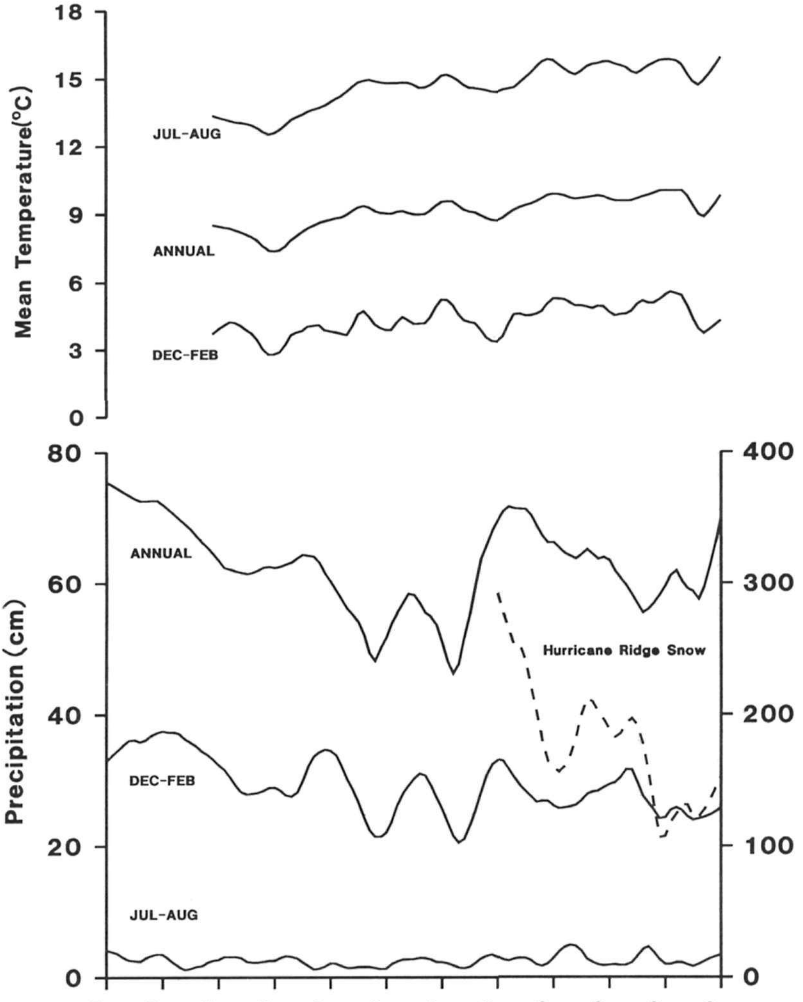


Fig. 4. Annual and seasonal trends in temperature and precipitation for Port Angeles, Washington, and 1 April snow depth (*dashed line*) for Hurricane Ridge, Olympic Mountains. Curves were smoothed using a locally weighted regression algorithm (LOWESS, Chambers et al. 1983) with the degree of smoothing set at $f = 0.10$ for all lines except July–August precipitation (0.07) and snow depth (0.20).

Climate differs across the peninsula. Mild maritime climates characteristic of the Pacific Coast give way to harsh cold in the alpine areas of the mountains, which in turn yields to dry, near-continental climate in the northeast (Fig. 5). The wettest location in the conterminous United States—the crest of the Olympic Mountain range—is less than 60 km from the driest west coast site north of southern California. Eighty percent of the annual precipitation on the peninsula occurs from October to March; only 5% occurs in July and August (Phillips and Donaldson 1972; National Oceanic and Atmospheric Administration 1978). Winter precipitation falls mostly as rain below 300 m, as rain and snow between 300 and 750 m, and as snow at higher elevations. The lowest recorded minimum temperatures at low-elevation stations are around –16 to –19° C; the highest, from 34 to 40° C. Average January temperatures are near 0° C, with August maxima around 21° C.

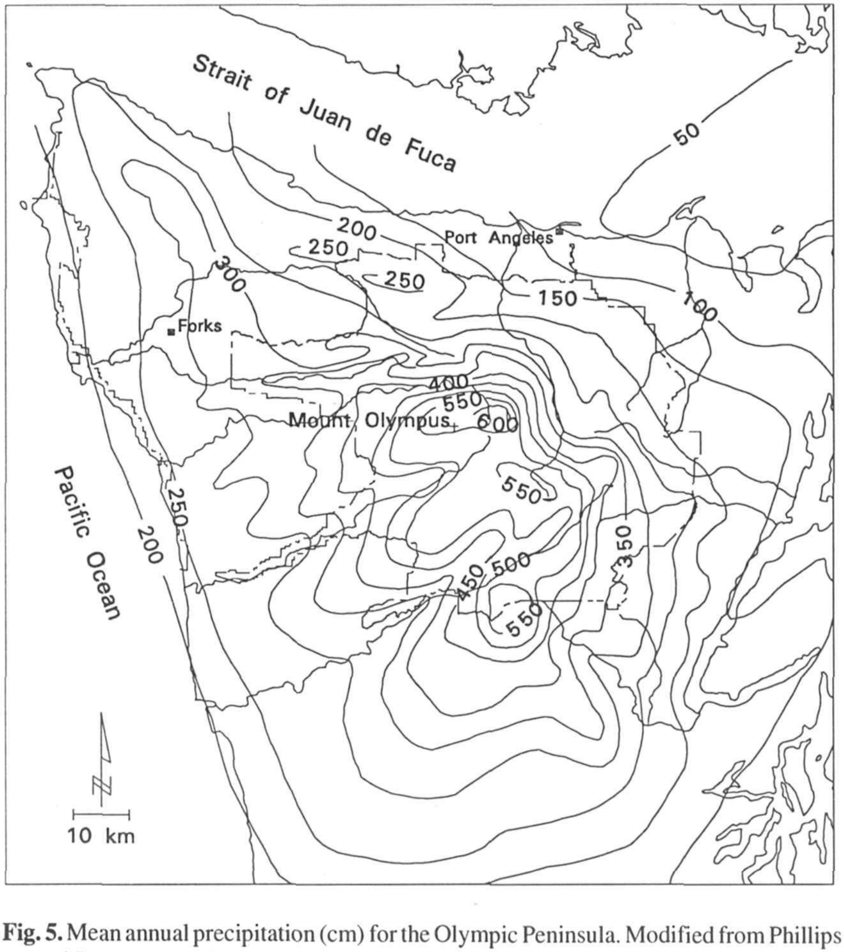


Fig. 5. Mean annual precipitation (cm) for the Olympic Peninsula. Modified from Phillips and Donaldson (1972).

The steep precipitation and elevation gradients of the mountains produce dissimilar microclimates in close proximity. For instance, a single ridge may be all that separates a permanent snowfield from hot dry habitats (Belsky and del Moral 1982). Moreover, dry alpine vegetation occurs within 15 km of oak savanna (now largely urbanized) and intertidal communities.

Vegetation

Pollen and macroscopic plant parts preserved in lake sediments and bogs have been used to infer the composition and distribution of plant communities that occurred in the Pacific Northwest since the Fraser Glaciation (summarized in Heusser 1977, 1978, 1983; Barnosky et al. 1987; Brubaker 1991; Whitlock 1992; Fig. 6). The species composition of plant communities was often so modified during glacial episodes that no modern counterparts exist (Whitlock 1992). The full glacial vegetation of 20,000–17,000 B.P. along the Pacific Coast contained elements of (but was not analogous to) the current subalpine parkland of the central Olympic Mountains. However, the composition of tundra–parkland in the Puget Trough, southeast of the Olympics, differed during this same period; there, the closest (albeit crude) modern analogue may be subalpine parkland of the northern Rocky Mountains. Forest composition has shown striking differences over time; the modern forests now characteristic of the Puget lowlands may not have been established until about 6,000 B.P. (Brubaker 1991; Whitlock 1992).

Coniferous Forests

Most of the peninsula below 1,520 m is coniferous forest (Fig. 7). Elevational boundaries between vegetation zones (sensu Franklin and Dyrness 1988) are a function of the east–west precipitation gradient (Fig. 8). Low-elevation forests over much of the western Olympic Peninsula fall within the Sitka Spruce Zone and typically contain Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*). The famous rain forests of west-side river valleys in the park (the temperate coniferous rain forest of Fonda 1974) are distinguished by massive Sitka spruce and western hemlock up to 90 m tall at densities of 60–270 trees/ha and by bigleaf maple (*Acer macrophyllum*) and red alder (*Alnus rubra*) laden with epiphytic mosses and ferns. The Western Hemlock Zone, often dominated by enormous Douglas-fir (*Pseudotsuga menziesii*) with western redcedar or western hemlock is the most common forest zone on the peninsula. The Western Hemlock Zone occurs on slopes above the Sitka Spruce Zone on the west side and is present at low and middle elevations elsewhere on the peninsula. The Pacific Silver Fir Zone typifies cool, relatively moist, middle-elevation forests of the western and southern portions of the peninsula. Silver fir (*Abies amabilis*) is characteristic, with a western hemlock component near lower elevation limits and mountain hemlock (*Tsuga mertensiana*) near upper

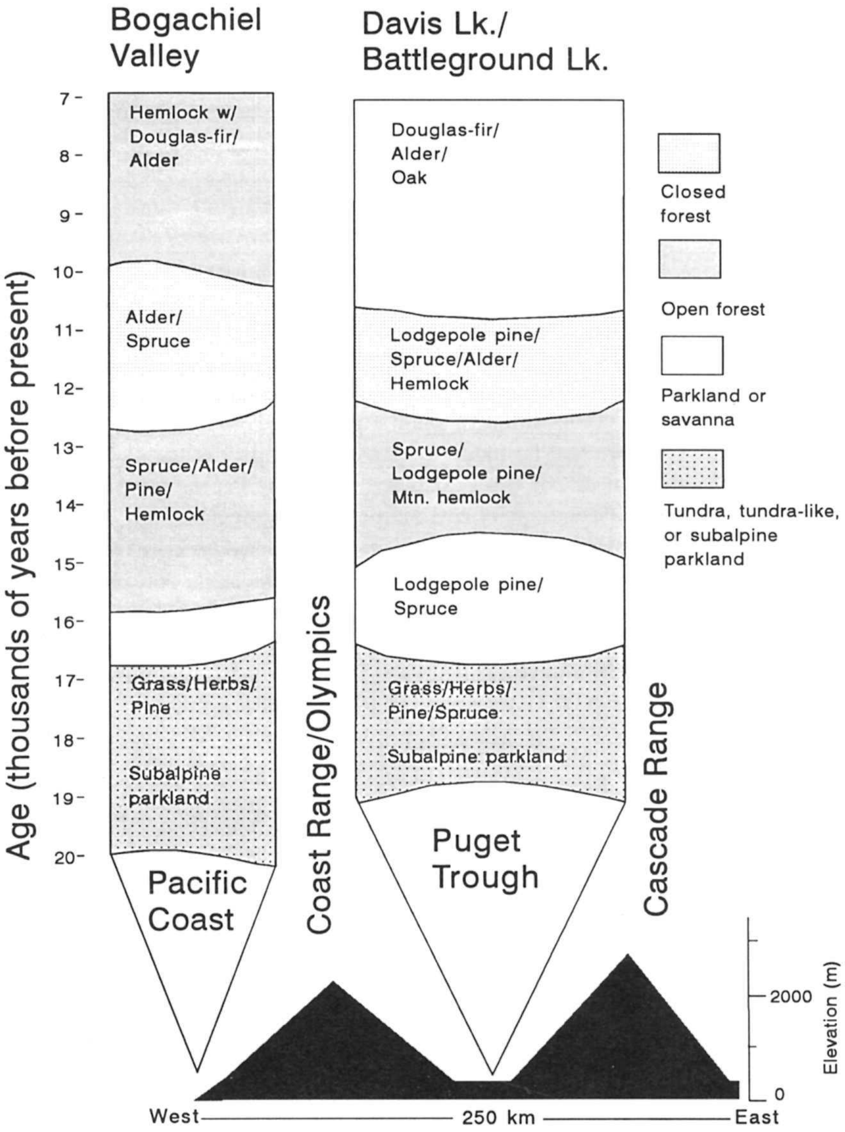


Fig. 6. Vegetation changes through time in western Washington, inferred from pollen analysis. Modified from Barnosky et al. (1987).

elevation limits. The south-facing slopes at middle elevations in the dry northeastern Olympic Mountains support Douglas-fir and have been classified either as a separate Douglas-fir Zone or as part of the Western Hemlock Zone (Henderson

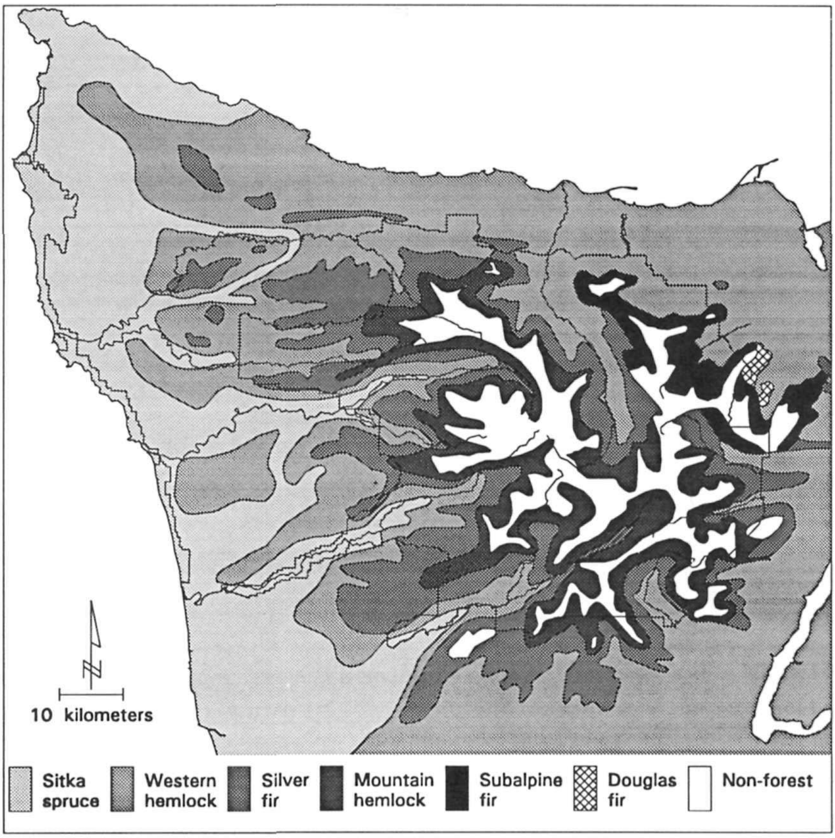


Fig. 7. Forest zones on the Olympic Peninsula. Modified from Henderson et al. (1989).

et al. 1989). Here, Douglas-fir-dominated forests grade into subalpine fir (*Abies lasiocarpa*) forests (i.e., the Silver Fir Zone is absent from these dry slopes).

Forests and tree clumps in the Subalpine Fir Zone of the dry northeastern Olympic Mountains are dominated by subalpine fir with components of lodgepole (*Pinus contorta*) or whitebark pine (*Pinus albicaulis*; Henderson et al. 1989). Meadows occur generally above 1,520 m in the zone and are dominated by grasses, forbs, sedges, spreading phlox (*Phlox diffusa*), or a few ericaceous shrub species. High elevation forests and tree clumps elsewhere in the Olympic Mountains generally include mountain hemlock, subalpine fir, and sometimes silver fir. These represent the Mountain Hemlock Zone. Ericaceous shrubs, forbs, and sedges dominate meadows in this zone.

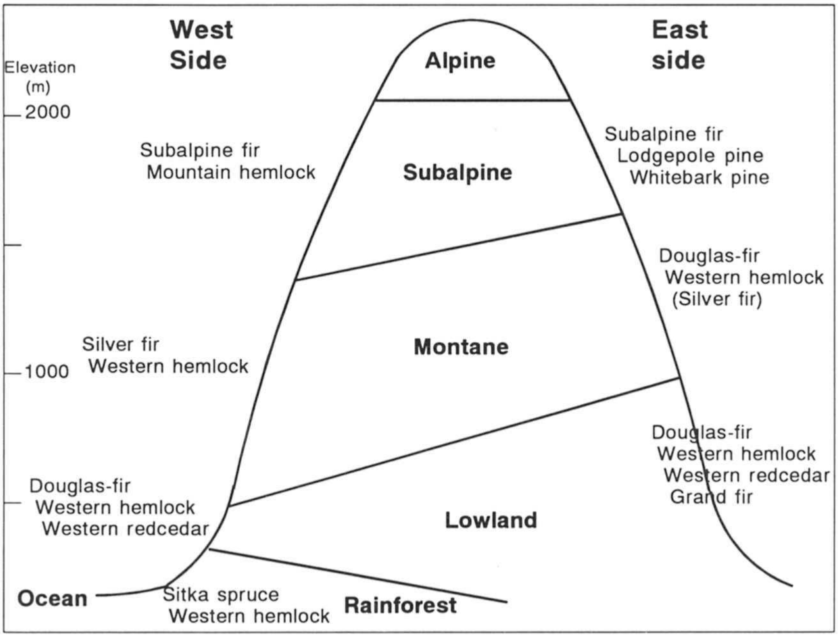


Fig. 8. Idealized vegetation zones on the Olympic Peninsula in relation to aspect and elevation.

Subalpine and Alpine Meadows

We identified 16 meadow communities in subalpine and alpine areas above 1,520 m (Fig. 9 and Appendix A1). Two communities with low total plant cover occurred at environmental extremes—one on highly disturbed, dry sites (*Astragalus*–scree); the other on raw substrates where snowmelt was late (*Luetkea pectinata–Saxifraga tolmei* community). Communities between these extremes seemed to be arrayed along a broad snowmelt and moisture gradient similar to that described by Kuramoto and Bliss (1970). Six community types on drier sites contained spreading phlox as a dominant or codominant species. Wetter sites were dominated by showy sedge (*Carex spectabilis*), pink mountain heather (*Phyllodoce empetriformis*), Merten's mountain heather (*Cassiope mertensiana*), or blueberry (*Vaccinium deliciosum*). Community composition was influenced by the relative stability of substrate, rock size, and glacial history. Our study extended the subalpine meadow work of Kuramoto and Bliss (1970) to steeper slopes and to the less meadowlike vegetation of rocky outcrops and talus slopes, and covered a larger geographical area than the regionally limited studies of Belsky and del Moral (1982), Pfitsch and Bliss (1985), and Smith and Henderson (1986).

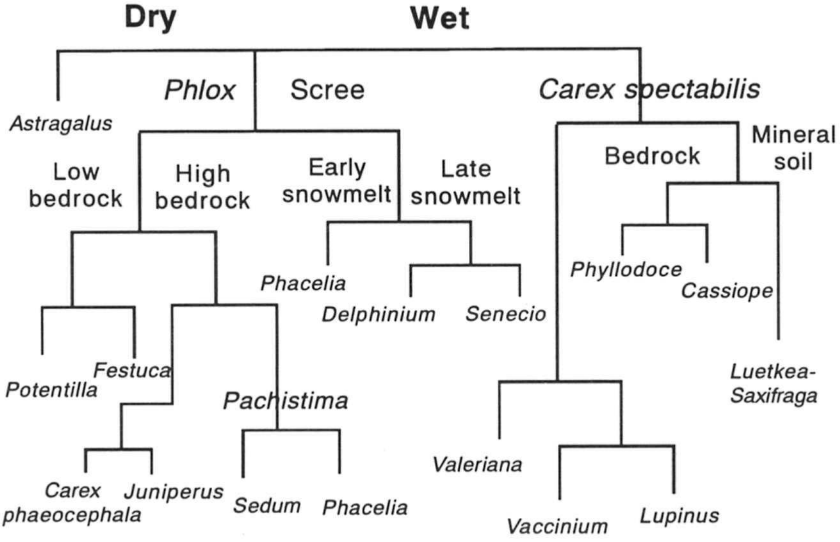


Fig. 9. Subalpine and alpine plant communities of the Olympic Mountains above 1,520 m.

Many environmental factors influence community composition in the subalpine and alpine zones. Earlier studies have shown that plant composition depends on snow retention (Bliss 1969; Canaday and Fonda 1974), temperature (Kuramoto and Bliss 1970), soil moisture (Kuramoto and Bliss 1970; Belsky and del Moral 1982; Pfitsch and Bliss 1985), magnitude of soil disturbance (Bell and Bliss 1973; Belsky and del Moral 1982; Pfitsch and Bliss 1985), microenvironment (Peterson 1971; Loneragan and del Moral 1984), and competitive interactions among species (del Moral 1983a, 1985). Soil moisture and disturbance are most often cited as influencing vegetation patterns. Mountain goats are most conspicuous in subalpine and alpine areas, but they occupy all vegetation zones (except Sitka spruce) at some season or place on the peninsula.

Settlement of the Olympic Peninsula

The abundant precipitation and acidic soils of the peninsula do not favor preservation of archeological materials—records of early human occupation are sparse and are likely to remain so (Wessen 1990). Scattered Clovis-type projectile points found around Puget Sound suggest that Paleo-Indians may have occupied the area by 11,000 B.P., but none of the points has been associated with dated archaeological deposits (Schalk 1988).

Human occupancy of the Pacific Northwest from 10,000 to 3,000 B.P. (the Old Cordilleran period) is somewhat better documented. On the peninsula, the oldest dated archaeological site from this time is a 5,000-year-old hearth located at 1,500 m in the northwest Olympic Mountains (Bergland and Marr 1988). People colonizing the area seem to have been derived from two distinct ethnic pools: groups that moved down the Columbia River from interior North America around 10,000 B.P. and bands that dispersed south down the coast about 9,000 B.P. (Bordon 1979; Carlson 1990).

More recent shell middens occur commonly in coastal areas and date from about 3,000 B.P. The middens and associated vertebrate remains suggest that semisedentary land use systems that evolved during the past 3 millennia were based on the exploitation of marine resources such as shellfish, fish, and marine mammals (Croes and Hackenberger 1988; Schalk 1988; Wessen 1990).

European contact with the Amerindian cultures of the peninsula occurred during the 1770's, if not earlier (Evans 1983; Capoeman 1990). As elsewhere in North America, aboriginal cultures were decimated by diseases of Europeans. By 1885, the Quinault population had declined to about 100 from the 1,000 of a century earlier (Capoeman 1990).

European settlement of the peninsula began in the 1850's; and by 1890 isolated settlements and homesteads were present throughout the low coastal areas (Evans 1983). The Olympic Mountains themselves evidently remained largely unexplored until the 1880's to 1890's (Appendix B).

Current Land Ownership and Use

Olympic National Park encompasses about 3,700 km^2 as two separate units—a central mountainous core of 3,530 km^2 and a narrow strip of 170 km^2 that extends for 84 km along the Pacific coast (Fig. 10). About 96% of the park is designated wilderness. Considerably less than 1% is developed with roads, trails, campgrounds, and structures that are located mainly around the periphery.

Lands surrounding the park are managed primarily for wood products by the Washington Department of Natural Resources (1,600 km^2), the U.S.D.A. Forest Service (Olympic National Forest—2,800 km^2), and private timber companies. Five Indian reservations also border the park. About 350 km^2 of the Olympic National Forest are also designated as wilderness. These wilderness parcels occur as six units abutting the eastern and southern boundaries of the park. Mountain goats are established only in the mountainous unit of the park and the adjacent Olympic National Forest, particularly in the wilderness blocks of the forest.

The epic struggle to establish the park pitted conservationists against politically powerful timber interests; Evans (1983) and Lien (1991) documented the stormy legislative history of the park. The core of the Olympic Mountains was included in a national monument created in 1909, but wrangling over the fate of potentially merchantable timber at lower elevations of the monument resulted in several subsequent boundary changes. The park has been administered since

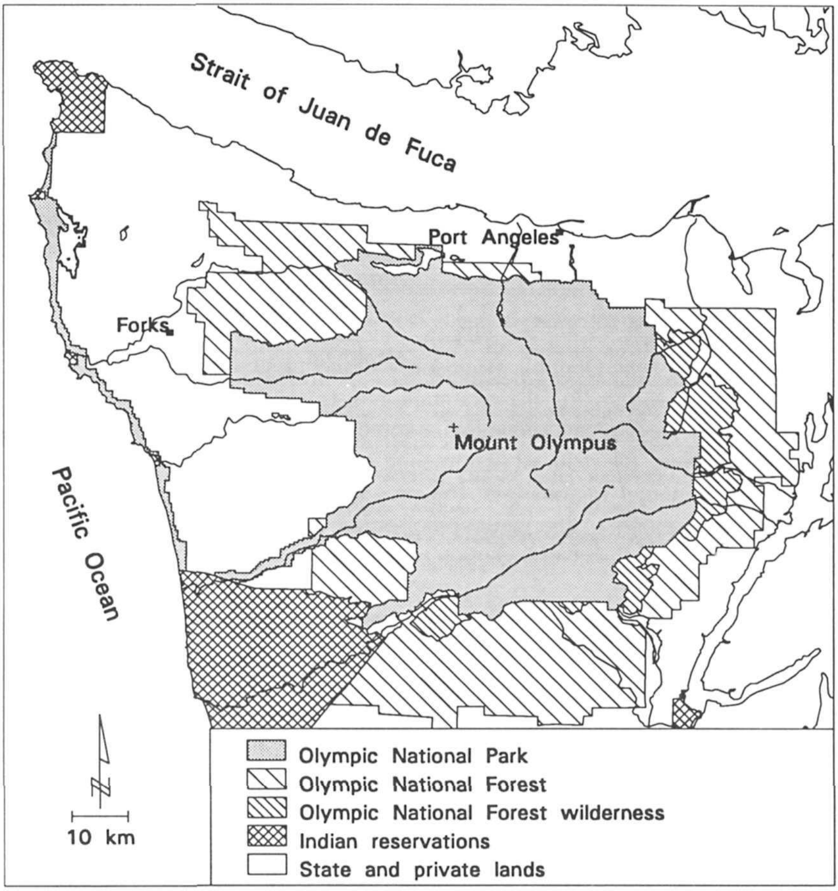


Fig. 10. Major landholders on the Olympic Peninsula.

its establishment in 1938 by the National Park Service, an agency authorized in 1916 (within the U.S. Department of the Interior), which developed policies for the management of the park (National Park Service 1988).

Chapter 3. Biogeography of the Olympic Peninsula

D. B. Houston, E. G. Schreiner, and N. M. Buckingham

Examination of the Olympic Peninsula's biogeography provides background necessary for understanding the mountain goat issue. The peninsula supports a unique assemblage of plants and animals; some points of interest are the evolution of endemic forms,[3] the reduced mammalian species diversity compared to more mainland continental regions, and the presence of plant taxa with intriguing distributions. Features of the geographic setting and the landscape-level events that have strongly influenced evolution of the Olympic biota include

1. the mountainous peninsular landform, sculpted repeatedly by glaciers of different origins and coverages;
2. the temporally varying isolation of the area as a peninsula and the associated changes in land mass as sea level and ice cover fluctuated (the Puget Trough lacked a marine embayment and the coastline was farther west during glacial maxima);
3. the strategic location of the peninsula at the southwestern corner of the massive Cordilleran ice sheet during the Fraser glaciation;
4. isolation of subalpine and alpine areas for at least 10 millennia as habitat islands in the mountain range, surrounded by forest and water (Barnosky 1984);
5. sharp precipitation and elevation gradients that have yielded a broad array of habitats within a comparatively small area; and
6. the moderating influence that the Pacific Ocean has on climate.

Endemic Organisms

Populations of plants and animals differing in appearance geographically and through time represent the substance of evolution. Assessing the degree of differentiation among populations is the substance of taxonomy and systematics. Differences between populations may be sufficient to warrant recognition of each as distinct biological species, the fundamental unit of evolution (Mayr 1963, 1970).[4] Less pronounced variation among populations may be recognized by designating subspecies and varieties and, for still lesser variation, races, ecotypes (mainly plants; Harper 1981; Merrell 1981; Kruckeberg and Rabinowitz 1985), or stocks (fish; Ricker 1972). Most degrees of variation—endemic species, subspecies, varieties, races, and stocks—have been described for the biota of the Olympic Peninsula. We are concerned primarily with variation at the level of species, subspecies, and varieties but occasionally note other forms described in the scientific literature.

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[3] Endemics are organisms whose distributions are limited to one geographic area. We emphasize taxa that are endemic to the Olympic Peninsula or to the peninsula and Vancouver Island.

Assessing levels of taxonomic differentiation may be difficult. The validity and meaning of biological species, subspecies, and varieties are debated among scientists (e.g., Mayr 1982, 1992). Accepted definitions of these terms change periodically and may differ among scientific disciplines (Futuyma 1979; Merrell 1981; Kruckeberg and Rabinowitz 1985; Geist 1991; Mayr 1992). We recognize these complex scientific issues, as well as the likelihood that criteria used to differentiate taxa are themselves evolving, particularly as analytical techniques become more sophisticated (e.g., analysis of DNA patterns). Nevertheless, 35 endemic forms of plants and animals are currently recognized on the Olympic Peninsula (Table 1).

Fifty-eight species of mammals occurred historically on the Olympic Peninsula (excluding marine mammals but including the gray wolf [*Canis lupus*], which was extirpated by 1930 and the white-tailed deer [*Odocoileus virginianus*], which was apparently eliminated by 1900).[5] Of these, five endemics are currently recognized, including one species and four subspecies. The three endemic rodents and the insectivore are associated with subalpine and alpine environments.

No endemic birds or reptiles are recognized, but one endemic amphibian, the Olympic torrent salamander (*Rhyacotriton olympicus*), has been recently described. Although the population of the Cope giant salamander (*Dicamptodon copei*) is centered on the peninsula, scattered, small populations also occur in southwest Washington and locally in Oregon streams that drain into the Columbia River Gorge (300 km distant). Consequently, the animal is not truly endemic (R. B. Bury, U.S. Fish and Wildlife Service, Fort Collins, Colorado, personal communication, 1992). The tailed frog (*Ascaphus truei*) in the Olympics may be sufficiently distinct to warrant recognition as a species, but additional genetics research is required (D. Good, Louisiana State University, Baton Rouge, personal communication, 1992).

Only one fish species is currently recognized as endemic—the Olympic mud minnow (*Novumbra hubbsi*). The resident cutthroat (*Oncorhynchus clarki*) and rainbow trout (*O. mykiss*) from Lake Crescent were described initially as species

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[4] In the Biological Sciences Concept, species are groups of interbreeding natural populations that are reproductively isolated from other such groups.

[5] Small numbers of white-tailed deer occurred historically in the Puget Lowlands; one specimen is known from the peninsula.

Table 1. Endemic fauna and flora of the Olympic Peninsula.

Common name	Scientific name	Source
	VERTEBRATES	
Mammals		
Olympic marmot	*Marmota olympus*	Hall 1981
Olympic yellow-pine chipmunk	*Tamias amoenus caurinus* [a]	Hall 1981
Olympic snow mole	*Scapanus townsendii olympicus*	Johnson and Yates 1980
Olympic Mazama pocket gopher	*Thomomys mazama melanops*	Hall 1981
Olympic ermine	*Mustela erminea olympica*	Hall 1981
Amphibians		
Olympic torrent salamander	*Rhyacotriton olympicus*	Good and Wake 1992
Fish		
Olympic mud minnow	*Novumbra hubbsi* [b]	Wydoski and Whitney 1979
"Beardslee" rainbow trout (lacustrine form)	*Oncorhynchus mykiss irideus* [c]	R. Behnke[d] 1992
"Crescenti" cutthroat trout (lacustrine form)	*Oncorhynchus clarki clarki* [c]	R. Behnke[d] 1992
	INVERTEBRATES	
Insects		
Lepidoptera—butterflies and moths		
Olympic arctic[e]	*Oeneis chryxus valerata*	Burdick 1957
Hulbirt's skipper	*Hesperia comma hulbirti*	Lindsey 1939
Orthoptera—grasshoppers		
Olympic grasshopper	*Nisquallia olympica*	Rehn 1952
Coleoptera—beetles		
Mann's gazelle beetle	*Nebria danmanni*	Kavanaugh 1981
Quileute gazelle beetle	*Nebria acuta quileute*	Kavanaugh 1979
Sylvan gazelle beetle[e]	*Nebria meanyi sylvatica*	Kavanaugh 1979
Johnson's snail eater[e]	*Scaphinotus johnsoni*	Van Dyke 1924
Tiger beetle	*Cicindela bellissima frechini*	Leffler 1979a
Millipedes		
Millipede[e]	*Tubaphe levii*	Causey 1954
Molluscs		
Arionid slug	*Hemphillia dromedarius*	Branson 1972
Arionid jumping slug	*Hemphillia burringtoni*	Pilsbry and Vanatta 1948

Table 1. *Continued.*

Common name	Scientific name	Source
	VASCULAR PLANTS	
Pink sandverbena[e]	*Abronia umbellata acutulata*	Kartesz and Kartesz 1980
Olympic Mountain milkvetch	*Astragalus australis* var. *olympicus*	Isely 1983
Piper's bellflower	*Campanula piperi*	Kartesz and Kartesz 1980
Flett's fleabane	*Erigeron flettii*	Kartesz and Kartesz 1980
Thompson's wandering fleabane	*Erigeron peregrinus peregrinus* var. *thompsonii*[f]	Kartesz and Kartesz 1980
Henderson's rock spirea	*Petrophytum hendersonii*	Kartesz and Kartesz 1980
Webster's senecio	*Senecio neowebsteri*	Kartesz and Kartesz 1980
Olympic Mountain synthyris	*Synthyris pinnatifida* var. *lanuginosa*	Kartesz and Kartesz 1980
Flett's violet	*Viola flettii*	Kartesz and Kartesz 1980
Olympic aster[e]	*Aster paucicapitatus*	Kartesz and Kartesz 1980
Magenta paintbrush[e]	*Castilleja parviflora* var. *olympica*	Kartesz and Kartesz 1980
Lance-leaf springbeauty[e]	*Claytonia lanceolata* var. *pacifica*	McNeill 1972
Blood-red pedicularis[e]	*Pedicularis bracteosa* var. *atrosanguinea*	Kartesz and Kartesz 1980
Tisch's saxifrage[e]	*Saxifraga tischii*	Skelly 1988
	CRYPTOGAMS	
Liverwort[e]	*Porella roellii* forma *crispata*	Hong 1987

[a] Trinomials indicate subspecies.

[b] Occurs south to Chehalis River.

[c] Formerly considered a distinct species; currently considered a lake-adapted form of the subspecies.

[d] R. Behnke, personal communication.

[e] Also occurs on Vancouver Island.

[f] Not found in Olympic National Park.

but are now considered lake-adapted forms of more widespread subspecies. Marked genetic differences separate stocks of anadromous salmon that spawn in the rivers of the peninsula (Reisenbichler and Phelps 1987), but these are not included in Table 1.

Endemism among Olympic invertebrates is difficult to assess because most groups are poorly known. We restrict consideration to several orders of insects and a few other groups whose taxonomy and distribution seem reasonably well understood. However, we regard even these interpretations as provisional. Currently, nine arthropods (eight insects, one millipede) and two mollusks are considered endemic to the peninsula or to the peninsula and Vancouver Island. The insects include five beetles (one species, four subspecies), two lepidopterans (subspecies), and one grasshopper (species). Five of the insects are associated with high montane or subalpine areas.

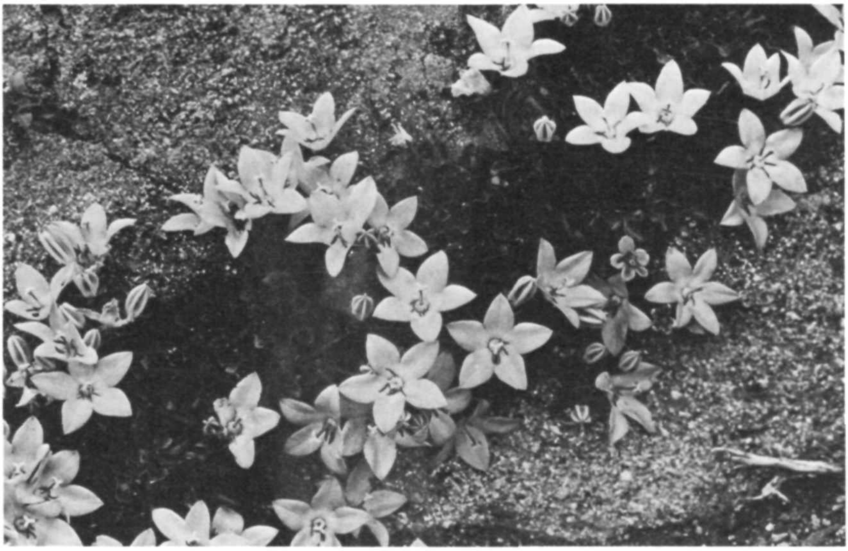
Fourteen vascular plant taxa are either endemic to the peninsula (eight; Fig. 11) or to the peninsula and Vancouver Island (six). Of these, Thompson's wandering fleabane (*Erigeron peregrinus* ssp. *peregrinus* var. *thompsonii*) occupies lowland swamps and bogs, and pink sandverbena (*Abronia umbellata* var. *acutulata*) was collected historically on the Olympic coast (now possibly extinct). All others (seven species, five subspecies or varieties) occur mainly in the alpine and subalpine zones.

The taxonomy and distribution of nonvascular plants and fungi are poorly understood. We know of no cryptogams (mosses, lichens, liverworts) or fungi that are endemic to the peninsula; however, one liverwort form is limited to the Olympic Peninsula and to Vancouver Island (Hong 1987). Preliminary inventories of alpine sites suggest that cryptogam diversity is unusually high in the Pacific Northwest—it seems reasonable that endemic forms will be discovered eventually (J. A. Henderson, U.S. Forest Service, Mountlake Terrace, Washington, personal communication, 1992).

Species Diversity

Animals

The terrestrial mammal fauna (48 species, excluding bats and marine mammals) of the Olympic Peninsula is impoverished compared to the nearby Cascade Range in Washington. Early naturalists and mammalogists reported 12 species absent from the Olympic Peninsula, although suitable habitat seemed to be present (Table 2). Species noted as absent, at least during historic time, consist of five carnivores, four rodents, a lagomorph (pika [*Ochotona princeps*]), and two ungulates, including the mountain goat. The red fox (*Vulpes vulpes*) and goat were introduced subsequently. The coyote (*Canis latrans*) reportedly colonized much of western Washington, including the Olympic Peninsula, during the early twentieth century—seemingly after gray wolf populations had been decimated (Dalquest 1948). Porcupines (*Erethizon dorsatum*) have been reported rarely during the past few decades; evidently a population has not become established.



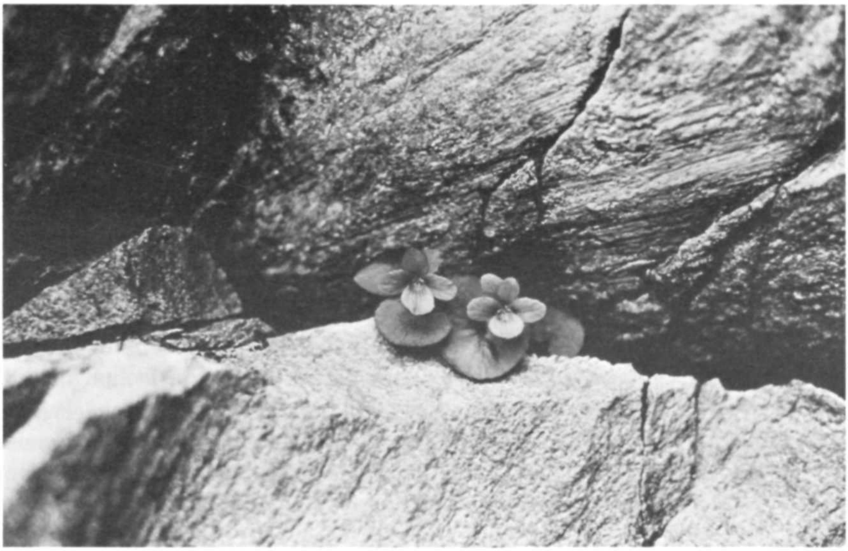


Fig. 11. The endemic *Campanula piperi* (bellflower; upper) and *Viola flettii* (Flett's violet) occupy rock crevices in the subalpine and alpine zones of the Olympic Mountains. The bellflower is known to be eaten by mountain goats. (National Park Service photos)

Table 2. Mammal and bird species present in the Cascade Mountains but absent historically from the Olympic Peninsula.[a]

Common name	Scientific name	Source
	Mammals	
Grizzly bear	*Ursus arctos*	D, J, M, S[b]
Wolverine	*Gulo gulo*	M, S
Red fox[c]	*Vulpes vulpes*	M, S
Coyote[d]	*Canis latrans*	M
Lynx	*Lynx canadensis*	J, S
Water vole	*Microtus richardsonii*	M, S
Golden-mantled ground squirrel	*Spermophilus lateralis*	D, J, M, S
Northern bog lemming	*Synaptomys borealis*	D, S
Porcupine[e]	*Erethizon dorsatum*	M, S
Pika[f]	*Ochotona princeps*	D, J, M, S
Mountain sheep	*Ovis canadensis*	D, M, S
Mountain goat	*Oreamnos americanus*	D, J, M, S
	Birds	
White-tailed ptarmigan	*Lagopus leucurus*	Sharpe[g]

[a] Scientific names from Honacki et al. (1982).

[b] D = Dalquest 1948; J = Johnson and Johnson 1952; M = Merriam (no date, circa 1897, Bancroft Library, University of California, Berkeley, unpublished notes and manuscript); S = Scheffer, Mammals of the Olympic Peninsula, Olympic National Park library, unpublished manuscript, 1949. (Note: Merriam compared biota of Olympic Mountains to that of Mount Rainier. He also considered gray fox [*Urocyon* spp.] to be absent, but that species was absent from the entire state.)

[c] Subsequently introduced (Aubry 1984).

[d] Colonized the Olympic Peninsula during the early twentieth century (Dalquest 1948).

[e] Occasional dispersing individuals, apparently no established population (Johnson and Johnson 1952; NPS unpublished records; Scheffer, Mammals of the Olympic Peninsula, Olympic National Park library, unpublished manuscript, 1949).

[f] Merriam found no pikas but was uncertain that they were entirely absent.

[g] F. A. Sharpe, Western Washington University, Bellingham, personal communication, 1992.

The avifauna of the Olympics also differs from that of the Cascades. The white-tailed ptarmigan (*Lagopus leucurus*) is absent, and seven other species common in the Cascades are currently known as either rare residents (spruce grouse [*Dendragapus canadensis*]) or as seasonal migrants and rare individuals without breeding populations, even though suitable nesting habitat seems to be present (dusky flycatcher [*Empidonax oberholseri*], mountain chickadee [*Parus gambeli*], mountain bluebird [*Sialia currucoides*], Nashville warbler [*Vermivora ruficapilla*], Cassin's finch [*Carpodacus cassinii*], Lincoln's sparrow [*Melospiza lincolnii*]; F. A. Sharpe, Western Washington University, Bellingham, personal communication, 1992; R. A. Hoffman, Olympic National Park, personal communication, 1992). Most records of these rare migrants are from the dry northeastern corner of the Olympics where some habitats seem analogous to the east slope of the Cascades. Possibly the amount of such habitat is currently insufficient to sustain viable, breeding populations.

Plants

Comparing the vascular plant diversity of the Olympics (~1,200 native taxa) to other areas is confounded by taxonomic bias (i.e., lumpers vs. splitters) in the regional floras (e.g., Alaska—Hulten 1968; Washington, Oregon, and Idaho—Hitchcock and Cronquist 1973; Canada—Scoggan 1978). These biases limit our ability to make comparisons as we did with birds and mammals. Nonetheless, the Olympic flora is notable for the absence of species common in the Cascades, as well as the presence of species not found in the Cascades. We limited comparisons to plants at high elevations that were identified from a common taxonomic source and to the conifers—a taxonomically stable group that represents the dominant vegetation.

Subalpine and alpine vascular floras of the Olympics and the North Cascades differ, but neither is necessarily more diverse (Pike 1981). Twenty-four percent of 1,054 native Olympic species were not found in the North Cascades; conversely, 36% of 1,248 North Cascade species were not found in the Olympics. Hitchcock and Cronquist (1973) was used to identify plants in both areas.

As with mammals, the Olympic coniferous flora (15 species) is impoverished compared to the Cascades. Five coniferous tree species found in the Cascades are absent from the Olympics (noble fir [*Abies procera*], ponderosa pine [*Pinus ponderosa*], subalpine larch [*Larix lyallii*], western larch [*L. occidentalis*], western juniper [*Juniperus occidentalis*]).

Other Taxa

We are reluctant to carry comparisons of taxa much beyond mammals, birds, and selected vascular plants because other components of the biota are less well studied. We note, however, that the distribution of butterflies is comparatively well known and that they too show reduced diversity; about 70 species occur in the Olympics compared to 124 in Washington's Cascades (Scott 1986; tallied by G. Hunter, Olympic National Park, personal communication, 1992). Additionally, Leffler (1979a) reported that tiger beetle (Coleoptera:Cicindelidae) diversity of the Olympics was surprisingly depauperate compared to mainland areas of the Pacific Northwest.

Patterns of Plant Distribution

Several plants found in the Olympics exhibit intriguing disjunct distributions, particularly some of those not found in the Cascades (Fig. 12). Western hedysarum (*Hedysarum occidentale*) occurs on the peninsula, on Vancouver Island, and

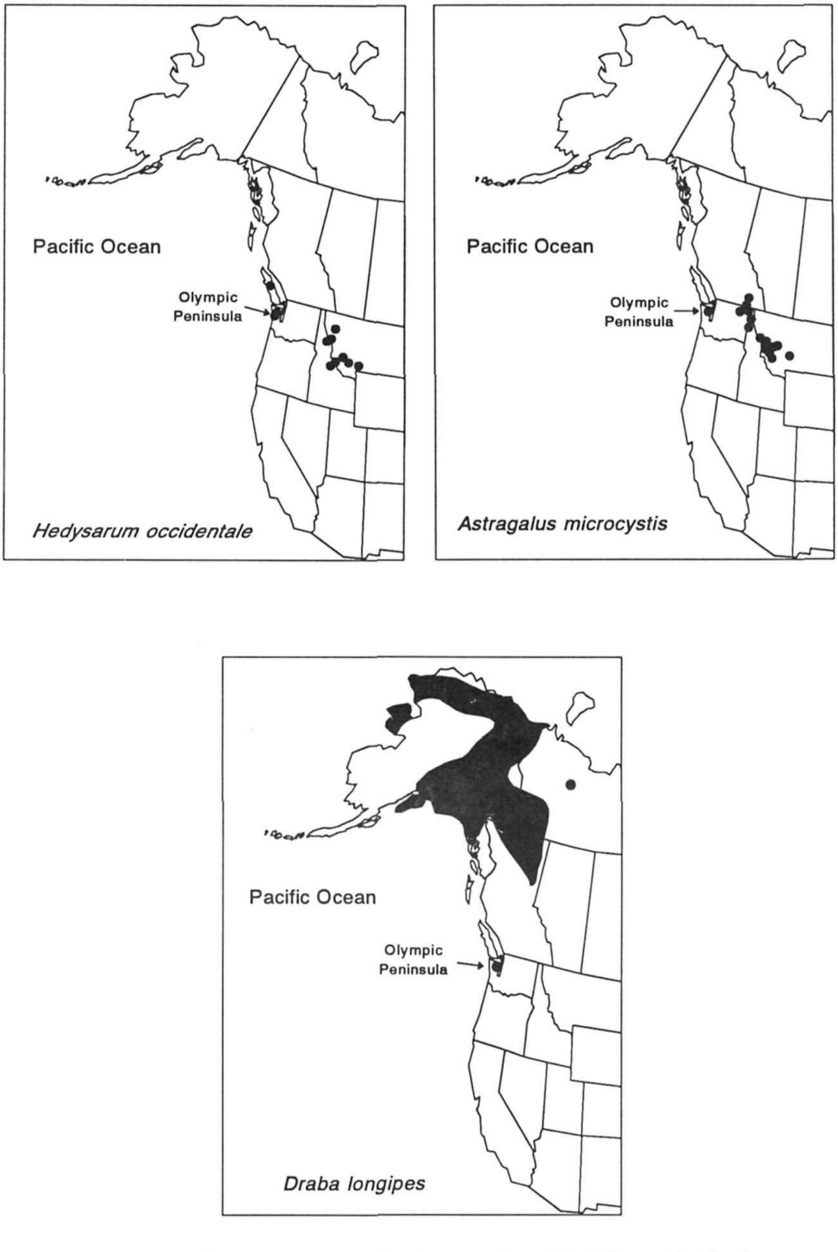


Fig. 12. Three examples of Olympic Peninsula plant species with disjunct distributions.

500 km east in the mountains of Idaho; least-bladdery milkvetch (*Astragalus microsystis*) occurs on the peninsula and from northeastern Washington (350 km east) into Idaho, Montana, and British Columbia; long-stalked draba (*Draba longipes*) is separated approximately 600 km from populations in northeastern British Columbia. The latter two taxa are known from only one or two locations in the subalpine and alpine zones in the dry northeastern Olympic Mountains.

Another phytogeographic pattern of interest includes plants at or near the southern extreme of their range along the Pacific Coast (Fig. 13). Deer cabbage (*Fauria crista-galli* ssp. *crista-galli*) occurs from the Olympics (and one point just south) along the coast to southeastern Alaska and the Kenai Peninsula. Cooley's buttercup (*Ranunculus cooleyi*) is present in the Olympics and in two populations in the Cascade foothills but occurs mainly from Vancouver Island north to the Queen Charlotte Islands. Large-headed sedge (*Carex macrocephala*) occurs along the coast from Oregon to the Alaska Peninsula and in Japan and China.

Preliminary investigations of the distribution of lichens reveal at least one on the peninsula (*Cetraria tilesii*) that is disjunct from the Rocky Mountains (K. Glew, University of Washington, Department of Botany, Seattle, personal communication, 1993). Also, several fungi are apparently disjunct from eastern North America (J. Ammirati and T. O'Dell, University of Washington, Department of Botany, Seattle, personal communication, 1993).

Interpretation

The biogeography of the Olympic biota, including the historical absence of mountain goats, can be viewed within the broader geographical context of the entire glaciated west coast of North America. About 15,000 B.P., the Cordilleran ice sheet extended along coastal North America from Alaska's Aleutian Range south through British Columbia to the Olympics (Fig. 14). Sea level was some 85–130 m lower than at present; consequently, large areas of the continental shelf were exposed (but mostly ice covered). Ice-free areas occurred as coastal refugia and nunataks (isolated mountain peaks projecting above the ice); these areas provided sites where populations of some plants and perhaps animals persisted.

Locally, the Olympics were partially overrun by ice on the northern and eastern sides, and the coastal plain extended 20–50 km farther west (see Fig. 3). South of the mountains, enormous, braided outflow channels from the Puget lobe of ice drained west into the Chehalis River and Grays Harbor (Waitt and Thorson 1983). Consequently, although still peninsular during full glacial times, the Olympic area may have been more insular in character, especially related to the dispersal of terrestrial animals. This condition persisted even after the ice began to retreat. During glacial retreat, the Puget Trough was occupied by a dynamic complex of large, proglacial lakes that also drained to the southwest until the ice melted beyond

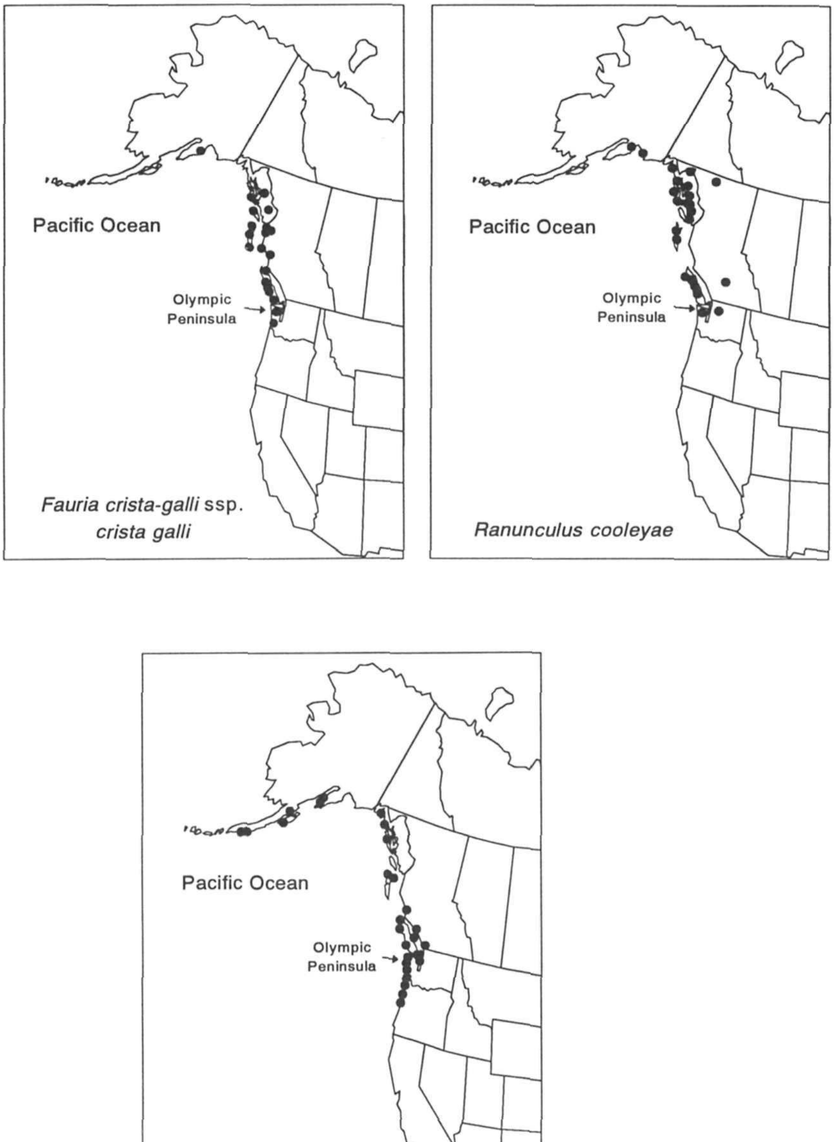


Fig. 13. Olympic Peninsula plants at or near the southern extreme of their range.

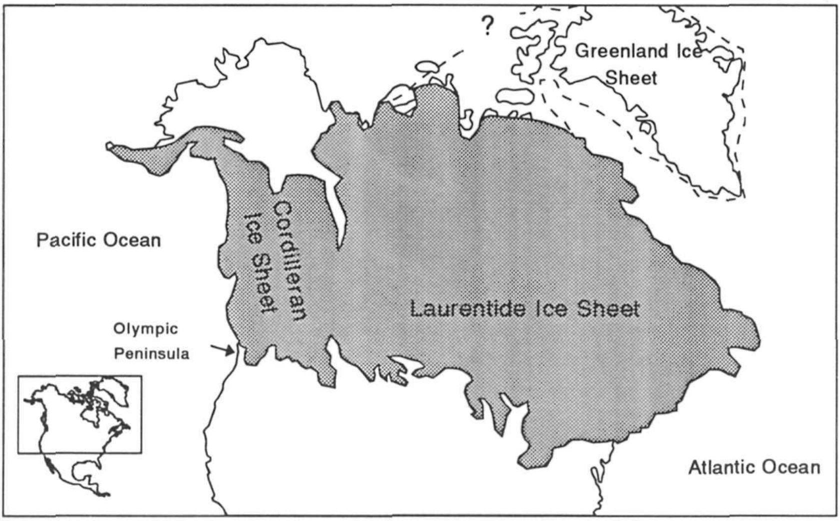


Fig. 14. The maximum proposed extent of Laurentide and Cordilleran ice ~~at approximately 10,000 B.P.~~ Modified from Denton and Hughes (1981) and Booth (1987).

the northeastern edge of the Olympics (about 13,000 B.P.), when the trough again became a marine embayment (Thorson 1980).

The familiar coastline of western North America did not emerge until 10,000–7,000 B.P. (most likely 8,400–8,000 B.P.; Mayewski et al. 1983) following melt of most of the ice and the consequent rise in sea level (Fig. 15). Before this, the currently existing islands along the coast (e.g., the Alexander and Queen Charlotte archipelagos, and Vancouver Island) were continental; today these are classed by biogeographers as landbridge islands because of the former connection.[6]

Endemism

Mammals

The degree of differentiation among terrestrial mammals on the Olympic peninsula (one endemic species, four subspecies) is roughly comparable to that of the landbridge islands. Thus, Vancouver Island has 1 endemic species (a marmot) and 11 subspecies; the Queen Charlottes had 1 species (extinct caribou)

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[6] The Kodiak archipelago in south-central Alaska apparently had no land bridge connection during late Wisconsin times (Karlstrom and Ball 1969; D. Mann, Department of Geology, University of Washington, Seattle, personal communication, 1992).

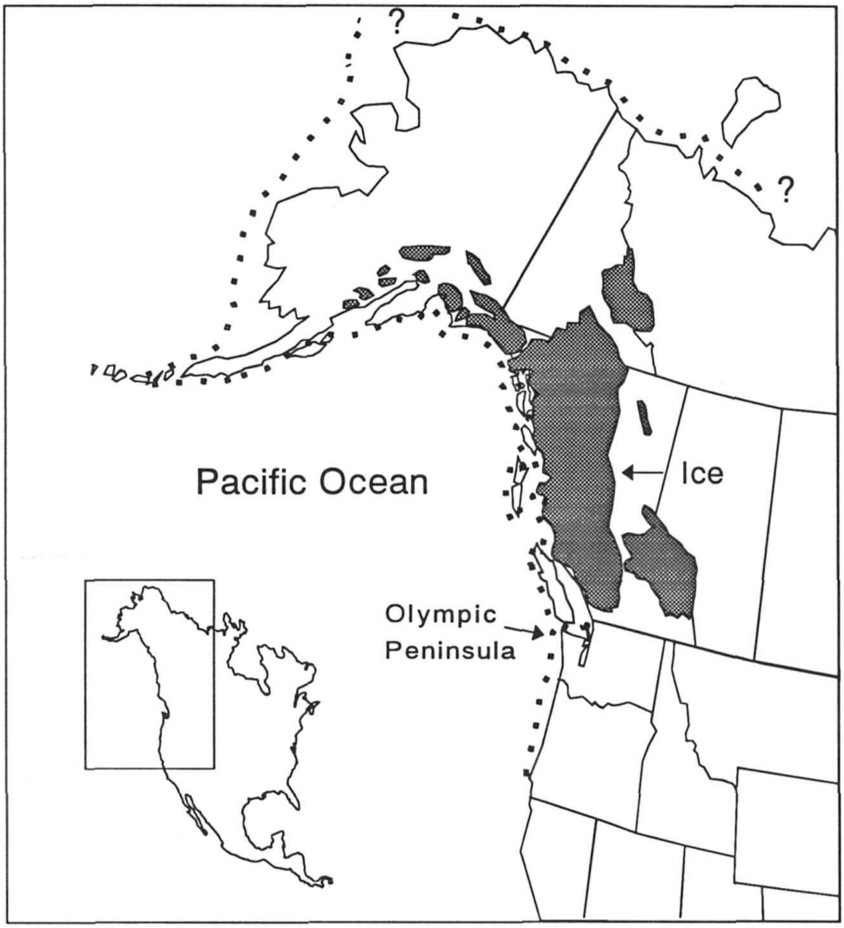

Fig. 15. The Pacific Northwest coastline (*dotted line*) and the Cordilleran ice at approximately 10,000 B.P., before separation of the landbridge islands. Modified from Mayewski et al. (1981) and Pielou (1991).

and perhaps 5 subspecies (others in dispute); the Alexander Archipelago has 11 subspecies (Hall and Kelson 1959; Cowan and Guiget 1965; Foster 1965).

Mammals are notoriously plastic genetically and, given a measure of isolation, are capable of differentiating into subspecies within just a few millennia or perhaps even centuries (Rausch 1969; Berry 1986). Much of the differentiation reported for the landbridge islands most likely occurred in less than 8,000 years. We do not know if any of the endemic mammals of the Olympic Peninsula persisted locally during the late Wisconsin glaciation or if all the differentiation occurred during post-Pleistocene time, which seems plausible.

Plants

The Olympic Peninsula and the landbridge islands all have endemic vascular plants: the Queen Charlottes have two (Newcomb's groundsel [*Senecio newcombei*] and Queen Charlotte violet [*Viola biflora* ssp. *charlottae*]); Vancouver Island has two (Macoun's meadow-foam [*Limnanthes macounii*] and wood lily [*Trilium ovatum* forma *hibbersonii*]; Szczawinski and Harrison 1972; Straley et al. 1985); and the Olympics eight. However, patterns of vascular plant and mammal endemism differ in that some endemic plants are shared among landbridge islands and the peninsula. Vancouver Island shares four endemic plants[7] with the Queen Charlottes and six with the Olympics. In addition, at least four coastal endemics occur within the area extending from southeastern Alaska to the Olympic Peninsula (swamp gentian [*Gentiana douglasiana*], copper bush [*Cladothamnus pyrolaeflorus*; Fig. 16], handsome shooting star [*Dodecatheon pulchellum* ssp. *macrocarpum*], and deer cabbage).

Plant geographers have categorized endemic plants as neoendemics (relatively new, like the peninsula mammals) or paleoendemics (relictual taxa that have existed for a very long, but indeterminate, time; Cain 1944; Stebbins and Major 1965; Daubenmire 1978; Kruckeberg and Rabinowitz 1985). The differences between the two types are believed to be tied to rates of evolution; rapidly evolving forms favor neoendemism, and slowly evolving forms favor paleoendemism (Daubenmire 1978). Debate continues as to how the two types can be differentiated (Kruckeberg and Rabinowitz 1985). We suspect that the Olympics contain plants in both categories, but detailed genetic and distribution studies are required before determinations can be made. Piper's bellflower (*Campanula piperi*), for example, may be paleoendemic because the closest related species occur more than 1,000 km north (Fig. 16). Conversely, Olympic Mountain groundsel (*Senecio neowebsteri*) may be a relatively new species because a closely related species exists in the nearby Cascade Range. In general, wide gaps in distribution are thought to characterize paleoendemics (Daubenmire 1978).

The evolutionary and biogeographical histories of the endemic vascular plants and animals on the peninsula may differ. Endemic forms of mammals may have evolved in situ on the peninsula. But the presence of endemic plants shared among the landbridge islands and peninsula suggests at least two other scenarios for plants: (1) taxa shared by two or more islands may have evolved on mainland North America as part of a larger metapopulation that was subsequently reduced, and (2) endemic plants evolved in situ in one location and dispersed to adjacent islands or the peninsula but not to the mainland. The first alternative may explain the overlapping flora of the Queen Charlotte and Vancouver Island archipelagos because the distance between the two is about

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[7] Calder's lovage (*Ligusticum calderi*), isopyrum (*Isopyrum savilei*), Schofield's avens (*Geum schofieldii*), and Taylor's saxifrage (*Saxifraga taylori*; Straley et al. 1985).

240 km, whereas from the mainland, the Queen Charlottes are only 80 km and Vancouver Island is less than 10 km. It is difficult to imagine plants dispersing 240 km and not crossing the shorter distances. The appropriate scenario for the shared Vancouver Island–Olympic endemics is not clear because all distances are comparatively short (20 km or less).

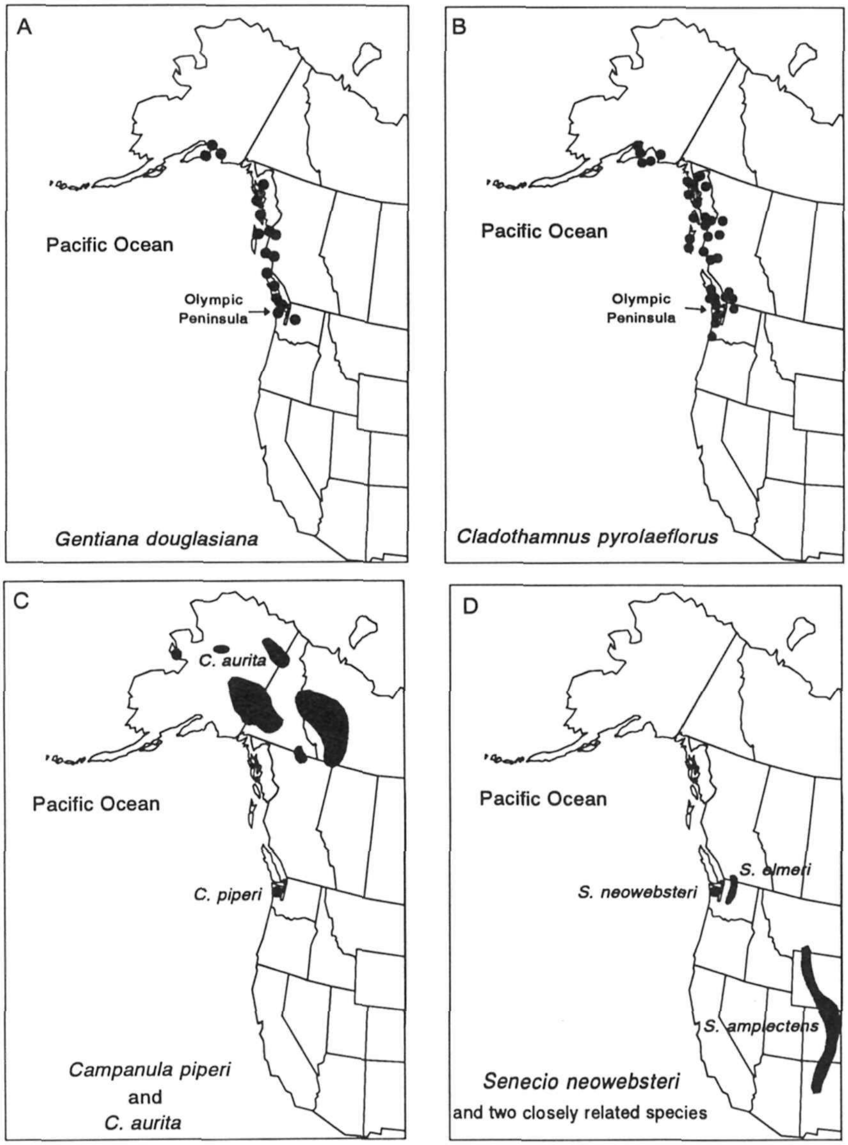

Fig. 16. Distributions of two Pacific Northwest coastal endemic plants (*A* and *B*) and two Olympic Peninsula endemics shown with their closest relatives (*C* and *D*).

Regardless of which evolutionary scenario is correct, endemic plants likely survived the last glaciation on nunataks or a coastal strip laid bare by the lower sea levels. Plant endemism is virtually unknown from mainland British Columbia,[8] which was covered by Cordilleran ice (Clague 1989). Nunataks and coastal refugia were important features on the Queen Charlottes and on Vancouver Island (Warner et al. 1982; Pielou 1991). The Olympic Peninsula was probably part of the same refugial system. Endemism in carabid beetles follows a similar pattern (Kavanaugh 1992).

Support for the nunatak–coastal refugium hypothesis also is found in the bimodal distribution by elevation of plants endemic to the peninsula. Two species occur at low elevations on the coast in areas thought to have been ice-free (Heusser 1977). The remaining endemics occur at elevations that exceed the maximum elevation of Cordilleran ice. We are uncertain of the extent of ice in the Olympics during the Evans Creek glacial period, but most high elevation endemics occur mainly on rock outcrops and ridge tops, which were likely free of ice and of persistent snow during that stade.

Species Diversity

Mammals

In common with the Olympic Peninsula, landbridge islands have impoverished faunas compared to the adjacent mainland (Table 3). Vancouver Island has 16 species of indigenous terrestrial mammals and 19 species that are absent (Cowan and Guiget 1965; Lawlor 1986). The situation on Alaska's Alexander Archipelago is more complex, but up to 18 species are absent from one or more of the islands compared to the mainland. The Queen Charlottes had only seven species of indigenous terrestrial mammals (wandering shrew [*Sorex vagrans*]; black bear [*Ursus americanus*]; marten [*Martes americana*]; short-tailed weasel [*Mustela erminea*]; white-footed mouse [*Peromyscus maniculatus*]; otter [*Lutra canadensis*]; and Dawson caribou [*Rangifer dawsoni*]; Cowan and Guiget 1965; Foster 1965).

Mammals missing from the landbridge island faunas include species that were absent historically from the Olympics as well—the mountain goat included. As with the Olympics, the mammal absences mean either that the species failed to colonize because of environmental barriers or that earlier populations met extinction. The success of deliberate introductions suggests that unoccupied habitat may exist for additional species. Six mammal species have been introduced successfully to the Queen Charlotte Islands: beaver (*Castor canadensis*), raccoon (*Procyon lotor*), black-tailed deer (*Odocoileus hemionus*), muskrat (*Ondatra zibethicus*), elk (*Cervus elaphus*), and red squirrel (*Tamiasciurus hudsonicus*). Three have been introduced to Vancouver Island: eastern cottontail

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[8] British Columbia has 14 endemic plants—10 occur on Vancouver Island and/or the Queen Charlottes; only 1 is found exclusively on the mainland (Straley et al. 1985).

Table 3. Terrestrial mammals absent from Vancouver Island and the Alexander Archipelago when compared to faunas on the adjacent mainland.[a]

Vancouver Island	Alexander Archipelago
Cinereus shrew, *Sorex cinereus*	Water shrew, *Sorex palustris*
Coast mole, *Scapanus orarius*	Collared pika, *Ochotona collaris*
American pika, *Ochotona princeps*[b]	Snowshoe hare
Snowshoe hare, *Lepus americanus*	Hoary marmot, *Marmota caligata*
Mountain beaver, *Aplodontia rufa*	Northern flying squirrel[c]
Northwestern chipmunk, *Tamias amoenus*	Northern bog lemming[b,d]
Bushy-tailed wood rat, *Neotoma cinerea*	Northern redback vole
Northern bog lemming, *Synaptomys borealis*[b]	Meadow vole, *Microtus pennsylvanicus*[e]
Boreal redback vole, *Clethrionomys gapperi*	Tundra vole, *Microtus oeconomus*[e]
Long-tailed vole, *Microtus longicaudus*	Muskrat
Muskrat, *Ondatra zibethicus*[f]	Meadow jumping mouse, *Zapus hudsonius*
Porcupine, *Erethizon dorsatum*[b]	Porcupine[b]
Coyote, *Canis latrans*	Coyote
Red fox, *Vulpes vulpes*[b]	Red fox[b]
Grizzly bear, *Ursus arctos*[b]	Wolverine, *Gulo gulo*[b]
Fisher, *Martes pennanti*	Lynx, *Lynx lynx*[b]
Spotted skunk, *Spilogale gracilis*	Moose, *Alces alces*
Striped skunk, *Mephitis mephitis*	Mountain goat, *Oreamnos americanus*[b]
Bobcat, *Lynx rufus*	
Mountain goat[b]	
Northern flying squirrel, *Glaucomys sabrinus*	

[a] Data from Cowan and Guiget 1965 and Manville and Young 1965.
[b] Also absent historically from the Olympic Peninsula.
[c] Absent from Chichagof, Admiralty, and Baranof islands only.
[d] Occurs only on Admiralty Island.
[e] Absent from Prince of Wales and Kuprenof islands only.
[f] Subsequently introduced.

(*Sylvilagus floridanus*), eastern gray squirrel (*Sciurus carolinensis*), and muskrat (D. Eastman, University of Victoria, Victoria, B.C., personal communication, 1992; D. Nagorsen, B.C. Provincial Museum, Victoria, B.C., personal communication, 1992). The mountain goat has been introduced to Baranof and Chichagof islands within the Alexander Archipelago and to Kodiak Island, and it has become established on at least Baranof and Kodiak (Ballard 1977) and in the Olympic Mountains.

Attenuated faunas characterize true islands, landbridge islands, and habitat islands worldwide (e.g., Heaney and Patterson 1986). Examination of the patterns of mammal distribution on islands has intensified during the past 2 decades. Most advances in understanding have resulted from testing observed patterns of distribution against the equilibrium model of island biogeography developed by MacArthur and Wilson (1967). Their model proposes that the number of species inhabiting an island represents a dynamic equilibrium between rates of colonization and rates of extinction and that the level of the equilibrium (species richness) may be predicted from knowledge of island size and degree of isolation. An enhanced understanding of mammalian biogeography occurred when the observed patterns refuted the predictions of the model (Brown 1986).

Generally, impoverished terrestrial mammalian fauna on landbridge and habitat islands are thought to represent nonequilibrium, relict faunas derived to a large extent from differential extinctions of formerly more widespread species (e.g., Brown 1971, 1986; Patterson 1984; Lawlor 1986). But questions remain, including the relative importance of extinction versus (failed) colonization in producing any particular assemblage of mammals, and the extent to which water and unsuitable terrestrial landscapes function as barriers to mammal colonization (Brown 1986).

The impoverished nature of the terrestrial mammalian fauna of the Olympics is to be expected. We do not know the relative contributions to the present fauna of extinction versus the failure to colonize. No obvious characteristics or relations have been identified that are common among species absent from the peninsula and from the landbridge islands that would similarly predispose populations to extinction (e.g., pikas [*Ochotona* spp.], bog lemming [*Synaptomys borealis*], porcupine, red fox, mountain goat). Density, demography, and ecological requirements differ widely among the five species. Failure to colonize might be as plausible an explanation as extinction in accounting for the absence of the four species (porcupine excepted) that occupy subalpine and alpine habitat; extensive bodies of water and forest may have represented effective barriers to colonization. Other regional examples of geographic barriers affecting mammal distribution include the greater richness of the terrestrial mammal fauna of western Oregon (10 additional species) compared to western Washington; the Columbia River apparently serves as an effective barrier to colonization (Dalquest 1948).

Plants

The overall diversity of vascular plants on the peninsula seems unremarkable when compared with the situation for terrestrial mammals. However, coniferous tree species diversity on the peninsula is reduced compared to the Cascade Range—a pattern of impoverishment similar to the mammals. We can not compare other taxonomic groups until the various floras are standardized.

Patterns of Plant Distribution

The disjunct and coastal distributions of vascular plants in the Olympics support geologic evidence for the occurrence of glacial refugia. We do not know how widespread these species were in the past, but their modern distributions seem to be limited to areas thought to have been ice-free during at least the

Vashon stade of the Fraser glaciation. For example, the long-stalked draba occurs in the Olympics and in what was southeastern and southern Beringia (Guthrie 1990; Pielou 1991). Western hedysarum, a western North America endemic, occurs in the mountains of Idaho just south of the former Cordilleran ice, on Vancouver Island, and in the Olympic Mountains.

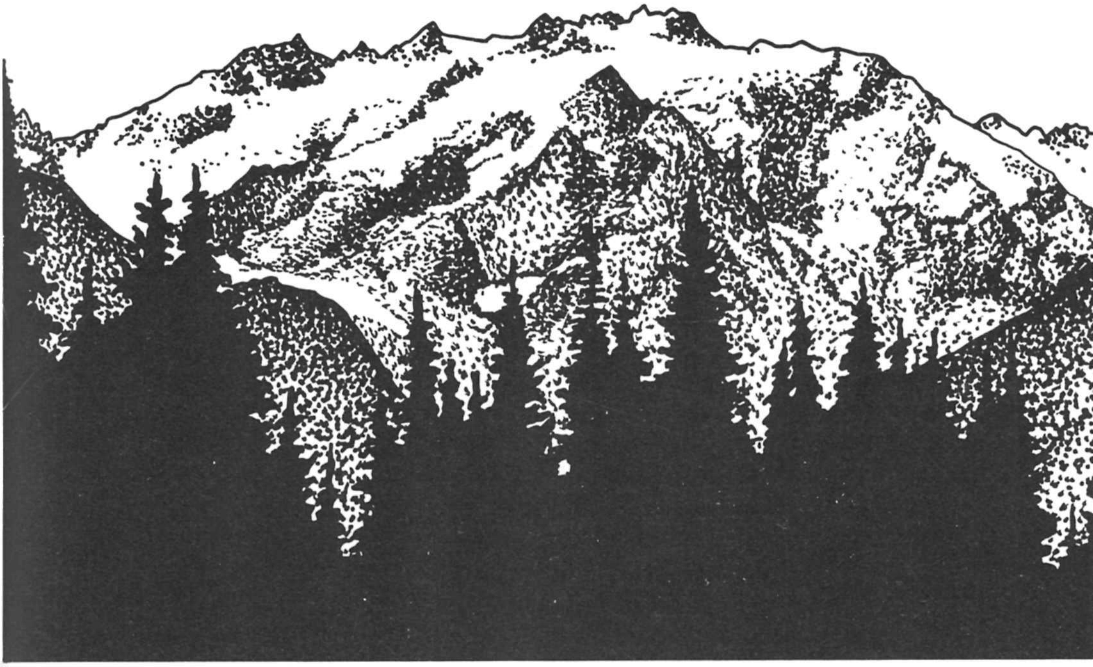
The distributions of closely related species also help interpret prehistoric events. Guthrie (1990) observed that the break in the distribution of closely related mammalian species such as pikas corresponded to the area covered by Cordilleran ice during the Vashon stade of the Fraser glaciation: He hypothesized that two species, *Ochotona princeps* and *O. collaris*, were a single taxon before invasion of the ice sheet and that they evolved into different species as a result of separation by the ice. A similar pattern is found in the distribution of species closely related to the endemic Piper's bellflower of the Olympics. The closely related bellflower (*Campanula aurita*) is found on the British Columbia–Yukon border and north—a distribution not unlike that of the pika. We do not know how long the *Campanulas* have been separated, but their distribution provides further evidence of glacial refugia in the Olympics.

Synopsis

Overall, species diversity and endemism characteristic of the terrestrial mammalian fauna on the Olympic Peninsula seem broadly comparable to landbridge islands along the glaciated west coast of North America. It is the particular assemblage of extant and endemic forms that renders the Olympic fauna unique. Species absent historically from the Olympics were also absent from landbridge archipelagos.

Endemism in vascular plants and the depauperate coniferous flora of the Olympic Peninsula is roughly similar to the patterns of mammals on landbridge islands. However, the shared endemism (among plants on the landbridge islands and the peninsula) and the occurrence of strongly disjunct plant species suggest that glacial refugia played an important role in phytogeography. Whitlock (1992) suggested that the Olympics could easily have provided the germ plasm for recolonization of the Puget Trough and points north as the Cordilleran ice receded. The Olympic biota is unique today and may well have served in the past as an important biological reservoir.

Mountain Goat Population



Chapter 4. History, Distribution, and Abundance

D. B. Houston, V. Stevens, and B. B. Moorhead

Introduction of Mountain Goats

Eleven or 12 mountain goats were released at Lake Crescent and nearby Baldy Ridge along the northern edge of the Olympic range at various times from 1925 through 1929 (Fig. 17). Moorhead and Stevens (1982) compiled historical information on the releases from newspaper accounts, correspondence, and notes in the files of Olympic National Park and Olympic National Forest. Official records are scant.

Four goats from British Columbia's Selkirk Mountains were released at the Lake Crescent site in January 1925 (Webster 1925; Port Angeles Evening News, 2 Jan. 1925). The records of subsequent releases are less clear (Webster 1932). In either 1927 or 1929, seven or eight goats from Alaska (two from the Chugach Range, six from Juneau) were released at Lake Crescent (five or six animals) and, perhaps, Baldy Ridge (two). Apparently, one of the Alaska animals died enroute. Early accounts refer to the goats as *pairs*, but no records of sex or age exist.

Dispersal and Colonization

The dispersal and subsequent colonization (i.e., establishment of breeding subpopulations) were also traced by Moorhead and Stevens (1982). During the 1930's, groups of up to 12 goats were occasionally reported on the slopes of Mount Storm King above Lake Crescent (Scheffer 1949; Port Angeles Evening News, 4 Nov. 1937). Goats dispersed from the release area and were seen on Mount Appleton in 1929 (13 km south), Mount Angeles in 1933 (25 km east), Constance Pass in 1931 (56 km west), and Mount Constance in 1935 (58 km east; Fig. 17). The U.S. Forest Service estimated the goat population at 25 animals in 1937—1 year before establishment of the park (Scheffer 1949).

Accounts suggest that by the early 1940's mountain goats occurred in small numbers in the northern mountains and along the eastern park boundary. By 1947, goats were observed annually on Mount Anderson, 49 km south of Lake Crescent. Before 1960, occasional sightings were reported on the Olympic National Forest south of the park and annually thereafter (C. Anderson, M. Beckstead, Olympic National Forest, Olympia, Washington, personal communication, 1979). These limited records suggest a dispersal east and south from the release sites of 3–6 km/year. Goats reached the eastern Olympic Mountains in 10 years and the southernmost mountains in 30 years.

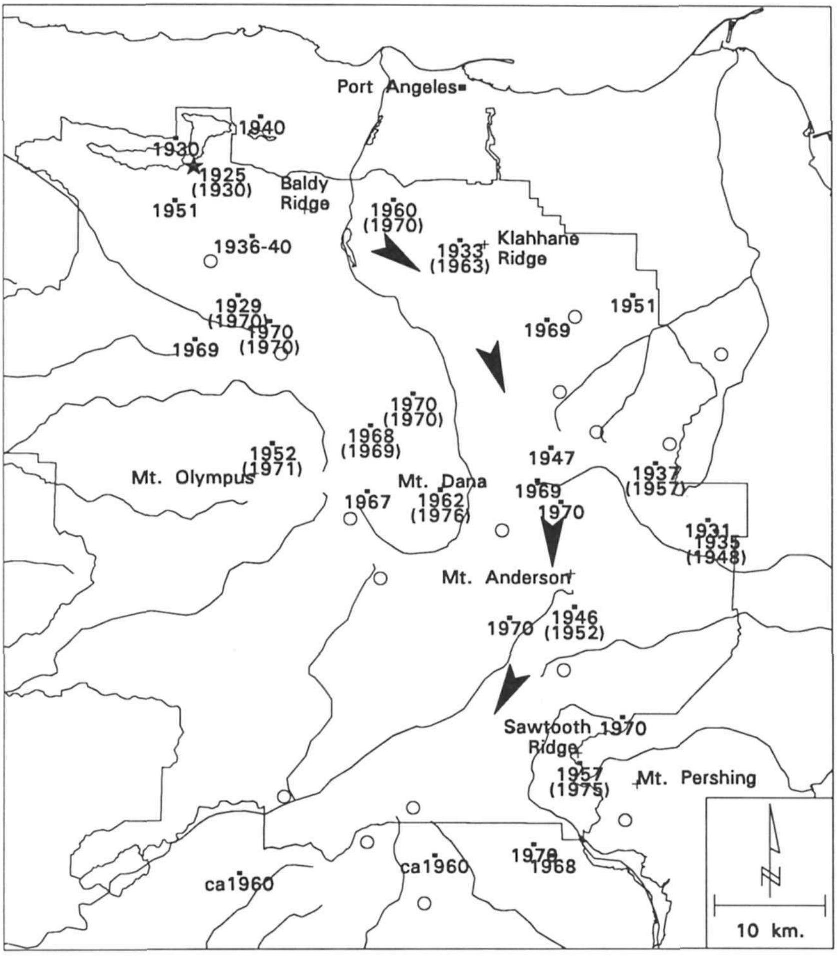


Fig. 17. Mountain goat dispersal and colonization of the Olympic Mountains. Shows the distribution of goats from their release in the 1920's (*starred*) through the 1960's and the year that females with young-at-heel were first reported (*parentheses*). ○ symbol shows expanded distribution of the 1970's. Modified from Moorhead and Stevens (1982).

During the 1970's, goats were reported in virtually all sectors of the mountains (Fig. 17). Few goats were reported in the central Bailey Range or around Mount Olympus until the middle-to-late 1960's. This central massif receives an estimated 380–500 cm of precipitation (mostly as snow) and may represent marginal habitat for the mountain goat. The most distant dispersal was a single animal reported in 1973 near Grisdale, 79 km south of Lake Crescent. By the late 1970's, goats were thought to occupy about 1,800 km^2 of the Olympic Mountains (Moorhead and Stevens 1982).

Distinguishing dispersal from true colonization is difficult with the available information. Studies have shown that young males (ages 1–3 years) are most likely to disperse (Stevens 1983). If that were the circumstance for pioneer dispersal throughout the range, it may explain the lags between dispersal and subsequent colonization (Fig. 17). For example, goats were first reported on the Mount Angeles–Klahhane Ridge area in 1933. Apparently, they either did not persist, remained at low densities, or did not establish a breeding population until the 1950's, because park records and newspaper accounts were still reporting the "first goat" on Mount Angeles as late as 1952 (Newman 1952; C. B. Browne, Olympic National Park, unpublished report). Glacier Meadows, north of Mount Olympus, was colonized as recently as 1981 (V. Stevens, personal observation). The sparse records available suggest that patterns of dispersal and colonization were complex.

Metapopulation

Observations of 237 tagged goats over 5 years led Stevens (1983) to view the goat population of the early 1980's as composed of reasonably discrete subpopulations. Dispersal occurred among subpopulations, and the comparative well-being of individual goats also differed among subpopulations. An assessment of the recent trend in numbers for the metapopulation (i.e., the overall population, composed of all the subpopulations; Andrewartha and Birch 1954) is available from rangewide aerial censuses conducted during 1983 and 1990.

Counting goats throughout an entire mountain range the size of the Olympics was formidable. The census design is described in detail elsewhere (Houston et al. 1986, 1991a). The census zone included all of the 50,063 ha of land free of glacial ice above 1,520 m in the Olympic Mountains. Most goats are seasonally migratory and visible mainly on subalpine ranges above 1,520 m during midsummer. About 87% of the area is within the park. A block count sampling method was used, and four census strata were recognized (Table 4). All known or suspected areas of high goat density and the Klahhane Ridge stratum were counted during both surveys. Known or suspected medium and low density areas were divided into blocks of about 500 ha each. Sample blocks were chosen randomly and censused. Aerial census is known to underestimate the actual number of mountain goats present, and a sightability bias of 0.66, developed from the goat removal program on Klahhane Ridge, was used to produce more accurate estimates (i.e., nearer the true total).

Based on actual counts of 448 goats in 1983 and 172 in 1990, we estimated the goat population in the census zone at 1,175 ± 171 (SE) and 389 ± 106 for the respective years (Table 4; Fig. 18). Despite the large standard errors, the 1990 metapopulation estimate differed significantly from 1983 (*t*-test

Table 4. Summary of mountain goat (*Oreamnos americanus*) censuses, Olympic Range, July 1983 and 1990.

	Area in ha		Area counted		Estimated goat numbers[a]	
Stratum	1983	1990	1983	1990	1983	1990
High density	5,071	6,229	5,071	6,229	173	131
Medium density	29,860(59)[b]	12,267(24)	14,251(28)	8,158(16)	882	151
Low density	13,135(26)	29,570(59)	2,847(6)	7,686(15)	35	104
Klahhane	1,997	1,997	1,997	1,997	85	3
Total	50,063	50,063	24,166	24,070	1,175 ± 171(SE)	389 ± 106(SE)

[a] Stratum estimates produced by multiplying numbers counted × 1.52 for visibility bias.

[b] Parentheses indicate number of 500-ha sample blocks available or sampled.

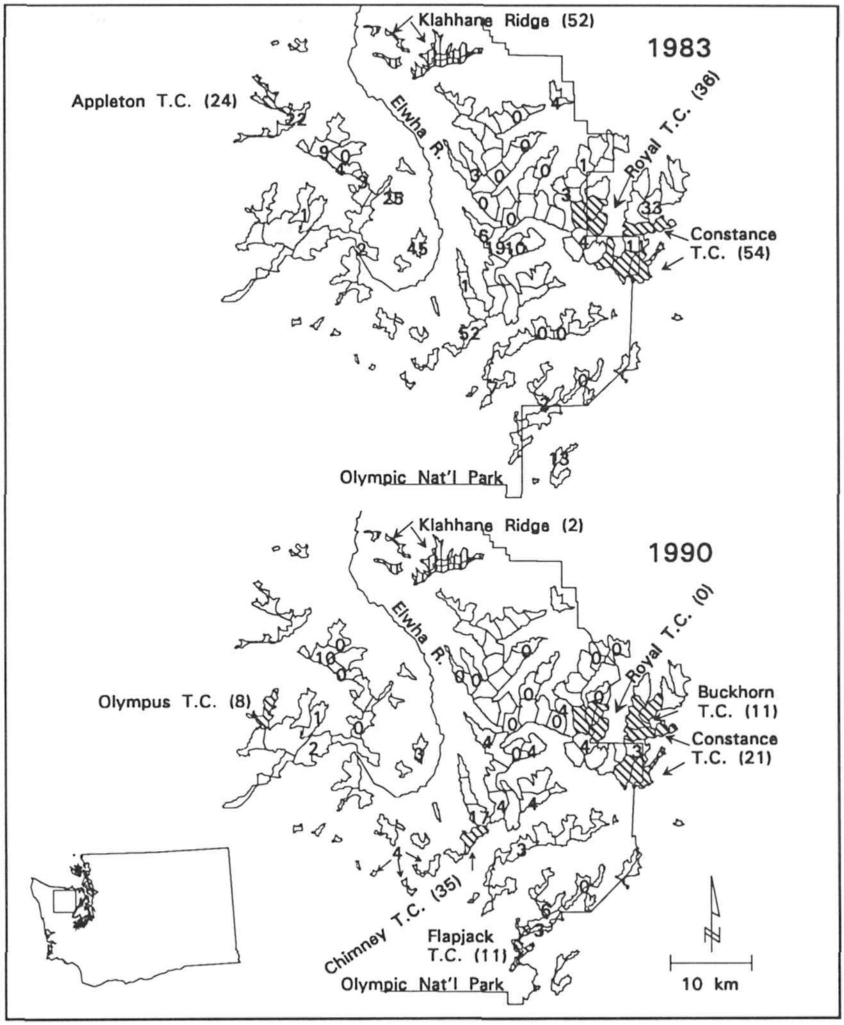


Fig. 18. Mountain goats counted per census unit, Olympic Mountains, July 1983 and July 1990. Total count (*diagonal hatch*), Klahhane Ridge, medium density (*shaded*), and low density (*open*) units are indicated. Extensive areas of glacial ice are not shown.

$\alpha_{0.05(2)}$, $t = 3.90$; Norton-Griffiths 1978:80; Gasaway et al. 1986:62), and we concluded that goat numbers declined considerably over the 7 years (the observed exponential rate of increase was $\bar{r} = -0.16$; Caughley 1977). Based on the 1983 census, the metapopulation may have increased from the late 1920's introduction to 1983 at a rate of $\bar{r} = 0.08$.

The contribution to the decline in goat numbers by the National Park Service removal program has been difficult to evaluate. Known goat removals totaled 326 from fall 1983 through fall 1989 (245 [75.2%] removed by National Park Service, 80 [24.5%] legally harvested outside the park, 1 [0.3%] illegally killed in the park). Annual removals were highly variable ($\bar{x}$ = 46.6 ± 34.7 SD goats/year, range 8–91).

Subpopulations

The quality of information on numerical trends differs markedly among subpopulations. We reconstructed reasonably complete pictures of growth trajectories for two subpopulations and provided general trends for others.

Klahhane Ridge

Goats inhabiting Klahhane Ridge (KR) range over about 3,900 ha year-round in the northeastern part of the park (Fig. 18). The goats migrate seasonally; some occupy winter ranges as low as 450 m in elevation. Summer ranges extend from about 1,400 to 1,968 m at the summit of Mount Angeles.

Goats seem to have colonized KR in the 1950's. By the early 1980's, the goats on KR were considered to be strongly limited by resources because they exhibited comparatively low reproductive rates, high dispersal, and slow body growth (Stevens 1983). The KR subpopulation was chosen for an experimental management program in 1981, largely because of the existence of background data, the high density of goats, and the relative ease of access. Goats were removed annually during 1981–84 as an experiment to measure response of the subpopulation to reduction (described below).

Goat numbers were determined using ground and aerial census (Houston and Stevens 1988). The 1977–81 estimates of goat numbers were calculated from ratios of tagged (n = 130) to untagged goats during ground censuses. The index manipulation index (IMI) method (Caughley 1977) was used to estimate the population during 1981–84, while goats were being removed. Subpopulation size was estimated by counts taken from helicopter (the index) following the June birth pulse before and immediately after a known number of goats was removed by trapping (the manipulation). On average, only 66% of the goats present were observed during the aerial censuses. Subsequent population estimates were made by adjusting the number actually counted by this value. Sufficient information was available for three early counts (1959, 1960, 1964) to also estimate sightability biases.

Thirty censuses of the KR population have been conducted from 1959 through 1990 (Table 5). About 180–200 goats were present in fall populations during 1977–80. Stevens (1983) considered that the KR subpopulation was essentially at ecological carrying capacity (K_l; Caughley 1976a) and that the

Table 5. Mountain goat (*Oreamnos americanus*) numbers and removals, Klahhane Ridge, 1959–1990.

Year	Census count	Population estimate	Month	NPS removals	Source and comments
1959	18[a]	31	9	0	Brent[b]
1960	11[a]	19	9	0	Brent[b]
1961				0	
1962	19[c]		6	0	Lack[d]; area counted was from Goat Peak to eastern slopes of Mount Angeles
1963	35[e]		7	0	Lack[d]
1964	36[c]	82	6	0	Lack[d]
	39[e]		7		
1965–70				0	
1971	29[c]		6	0	Moorhead[f]
1972	41[g]		5	4	Moorhead[f]; NPS records: trapped/removed
	19[c]		10		
1973				4	Moorhead[f]; NPS records: trapped/removed
1974	59[a]		6	4	Moorhead[f]; NPS records: trapped/removed
1975				9	NPS records: trapped/removed
1976	135[e,h]		9	9	Moorhead[i]; 6 trapped/removed, 1 illegal kill, 2 collected as biological specimens
1977	Cumulative[e]	181	9–10	4	Stevens 1983; NPS records
1978	Cumulative[e]	131	9–10	0	Stevens 1983; NPS records
1979	Cumulative[e]	179	9–10	4	Stevens 1983; NPS records
1980	Cumulative[e]	222	9–1	2	Stevens 1983; 2 collected as biological specimens
1981	Cumulative[e]	170	6	60	June and October estimates from Stevens 1983
	154, 152[a]	229[j]	6		Removals: 7 collected as biological specimens,
	117, 112[a]	171[j]	7		1 illegal kill, 52 trapped/removed
	Cumulative[e]	183	10		

Table 5. *Continued.*

Year	Census count	Population estimate	Month	NPS removals	Source and comments
1982	78[c]		6	51	51 trapped/removed
	125[a]	176[j]	6		
	89[a]	126[j]	7		
	74[a]		9		
1983	90[a]	147[j]	6	53	52 trapped/removed, 1 illegal kill
	52[a]	85[j]	7		
1984	48[a]	80[j]	6	19	19 trapped/removed
	36[a]	60[j]	7		
1985	24[a]	36[j]	6	4	Collected as biological specimens
1986	27[a]	41[j]	6	0	
1987				0	
1988				17	Captured and removed
1989				3	Captured and removed
1990	2[a]	3	7	0	

[a] Helicopter count; 1959 and 1960 estimates calculated using observability of 0.59; 1990, 0.66.

[b] H. Brent, helicopter goat counts, Washington Department of Game, Olympia, unpublished reports, 1959, 1960.

[c] Fixed-wing aircraft count; 1964 estimate calculated using observability of 0.44.

[d] L. Lack, goat ecology studies, Olympic National Park, unpublished field notes, 1962–64.

[e] Ground count.

[f] B. B. Moorhead, aerial counts of mountain goats, Olympic National Park, unpublished report, 1971–74.

[g] Census method unknown.

[h] Area surveyed did not include Hurricane Hill.

[i] B. Moorhead, cooperative goat census on Mount Angeles, Olympic National Park, unpublished report, 1976.

[j] IMI estimate; see text for explanation.

goats did not undergo the eruptive overshoot and crash typical of colonizing ungulates (Caughley 1970a). Population growth from establishment through 1980 may have occurred as shown in Fig. 19; $\bar{r}$ was about 0.09 for 1959–80. Similar calculations using the three adjusted counts for the 1959–64 period of initial population growth returned an $\bar{r}$ of 0.24 ± 0.14 (SE). This represents a crude estimate of r_m, the intrinsic rate of increase (Caughley and Birch 1971), which is a measure of population growth when, presumably, no resource is in short supply.

Different census techniques produced comparable results. Ground counts and calculations using tagged goats produced an estimate of 183 goats during fall 1981, reasonably close to the IMI estimate of 171 for the mid-July population (Table 5; Fig. 19). The IMI estimate of the 1981 birth pulse population also seems reasonable when compared with fall populations in 1977–80. Fall estimates reflect declines due to dispersal and kid deaths (Stevens 1983).

Park records showed that 247 goats were removed from the KR subpopulation in 1959–89 (Table 5; Fig. 19). About 93% were live-trapped and translocated, 6% were collected as biological specimens, and 1% were illegal kills. Forty goats were removed between 1972 and 1980 ($\bar{x}$ = 4.4 ± 2.9 SD/year). If birth-pulse populations were around 220, then removals represented annual human predation of about 2%.

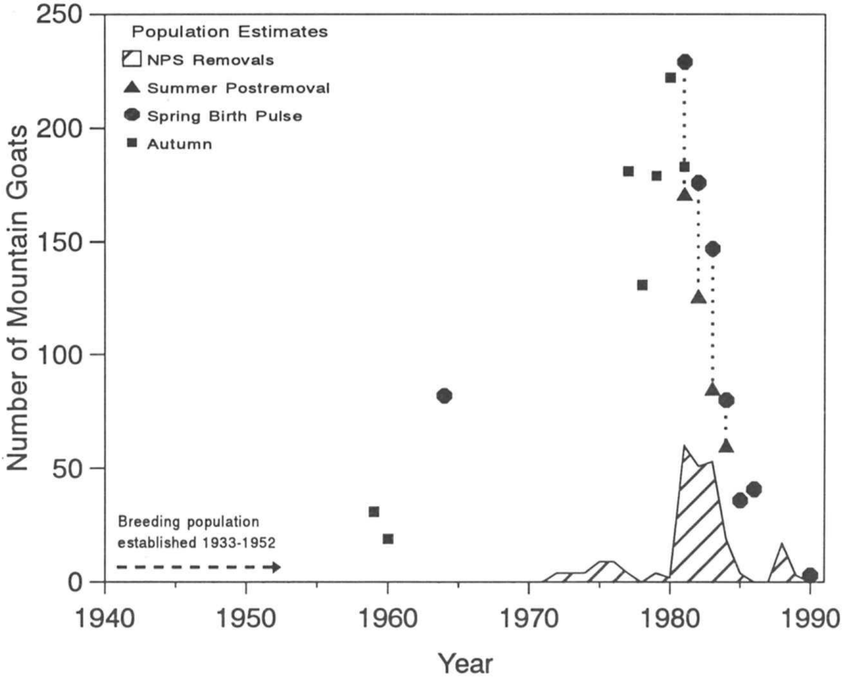


Fig. 19. Population estimates and removals for the Klahhane Ridge mountain goats.

During 1981–84, we attempted to exploit the KR goats at a level equal to the estimated mean production of young in the prereduction populations; 48 ± 25 SD kids occurred in late June populations in 1977–80, and about 46 ± 20 in fall populations. About 29 ± 5 yearlings occurred in June populations from 1977 to 1980. Beginning with the June 1981 population of 229 goats, an average of 52 (range 51–52) goats was removed annually for 3 years. Removals exceeded the average June estimate of young by four, and the fall estimate by six. Removals exceeded the mean number of yearlings in June by about 23 animals. Attempts to remove another 52 goats in 1984 failed when only 19 were captured. At this level of removal, numbers declined at $\bar{r} = -0.33$ to an estimated 80 goats in the preremoval population of June 1984. Four additional goats were collected for necropsy in late winter 1985. The birth-pulse populations of 1981 declined at $\bar{r} = -0.40 \pm 0.06$ SE to an estimated 41 goats by 1986.

Management direction changed from experimental to operational in 1988, and 20 additional goats were removed by 1989. Overall, the population of 1981 declined at $\bar{r} = -0.49$ to an estimated three goats by 1990. National Park Service removals were the main force driving the decline of the KR goats, but environmental factors played a role, as goat numbers seemed to continue to decline even when removals were suspended during 1985–87.

Conceivably, a large reduction in numbers could occur without enhancing per capita resources if goats have strong affinities for local sites (e.g., Kuck 1977). However, our observations indicated that even at low densities, the KR goats continued to distribute themselves throughout the area in summer and winter, albeit in smaller groups. This suggested that per capita resource levels were much greater at the low goat densities, a circumstance that had important implications for the population's dynamics (see Chapter 5).

Baldy Ridge

One of the first subpopulations of goats to become established in the Olympics was in the Baldy Ridge area, about 5 km from the site of introduction. A substantial portion of the Baldy Ridge subpopulation frequented the extensive cliffs along Hughes Creek during winter and spring, where they were observed easily from the Elwha River road. Most goats leave the cliffs by late spring, but we know little about summer or fall distribution. None of the 254 goats tagged or radio-instrumented elsewhere in the park during summers from 1977 to 1986 was observed wintering on the Hughes Creek cliffs (R. Hoffman, personal observation; V. Stevens, personal observation).

Sixty-two ground counts were available for November–April periods from 1953 to 1988, including 12 years with multiple counts (Table 6; Fig. 20). Although the variation among annual counts was sometimes great, numbers observed declined substantially over the 37 years. The rate of decline was calculated as $\bar{r} = -0.08$ based on the maximum annual counts for years with multiple counts. Five aerial counts confirmed the trend observed from the

Table 6. Mountain goat (*Oreamnos americanus*) numbers and removals, Baldy Ridge–Hughes Creek, 1953–1990.

	Count				
Year	Mean ± SD	Maximum (no. counts)	Month	NPS removals	Source and comments
1953[a]		18(1)	12		National Park Service 1953
1954		12(1)	12		National Park Service 1954; 7 adults, 5 kids
1955	20 ± 4.4	25(3)	12		Newman[b]; kids present
1963	17 ± 6.8	27(6)	11–3		Lack[c] 1963
1964	19 ± 2.9	23(4)	2–4		Lack[c] 1964
		17[d]	6		
1970	16 ± 5.6	20(2)	1–4		Moorhead[e] 1970; kids present
1971		14[d]	1		Moorhead[e] 1971; kids present
1972		8(1)	1		Moorhead[e] 1972; kids present
1973	9 ± 1.4	10(2)	11–1		Moorhead[e] 1973; kids present
1974	12 ± 3.5	14(2)	4		Moorhead[e] 1974; kids present
1976	6 ± 4.6	13(9)	3–4		Hays[f]; kids present
1977	6 ± 2.5	8(8)	11–3		Hays[f]
1982	3 ± 1.1	4(11)	1–4		Seaman[g]; all adults
1983	4 ± 0.8	5(5)	12–3		Houston[h]; all adults
		5[d]	3		all adults
1985		2(3)	4		Houston[h]; all adults
		3[i]	5		all adults
1988	2 ± 0.6	2(3)	3	1	Moorhead[e] 1988; all adults
1990		2[h]	5		Olson[j] 1990; all adults

[a] 1953 = winter 1952–53, etc.

[b] C. Newman, Field notes, Olympic National Park, unpublished report.

[c] L. Lack, Goat ecology studies, Olympic National Park, unpublished field notes.

[d] Counts from fixed-wing aircraft.

[e] B. B. Moorhead, Olympic National Park, unpublished reports.

[f] L. Hays, Mountain goats on Baldy Ridge–Hughes Creek, Olympic National Park, unpublished field notes.

[g] D. E. Seaman, unpublished data, 1982.

[h] D. B. Houston, Olympic National Park, unpublished data, 1983.

[i] Counts from helicopter.

[j] R. W. Olson, Olympic National Park, unpublished data.

ground. This decline could represent either reduced observability as forest cover increased on Baldy Ridge, a real decline in numbers of goats, or both.

The ridge burned during the late nineteenth century, and a photo taken in March 1907 compared to 1983 shows a substantial increase in forest cover (Fig. 21). Additionally, park records show that a small fire occurred on the crest of Baldy Ridge between 1916 and 1939 and that in 1950 another 120 ha burned on the north slopes below the ridge top. Lack (1962) reported that grasses throughout the burns had been heavily grazed by goats during 1962.

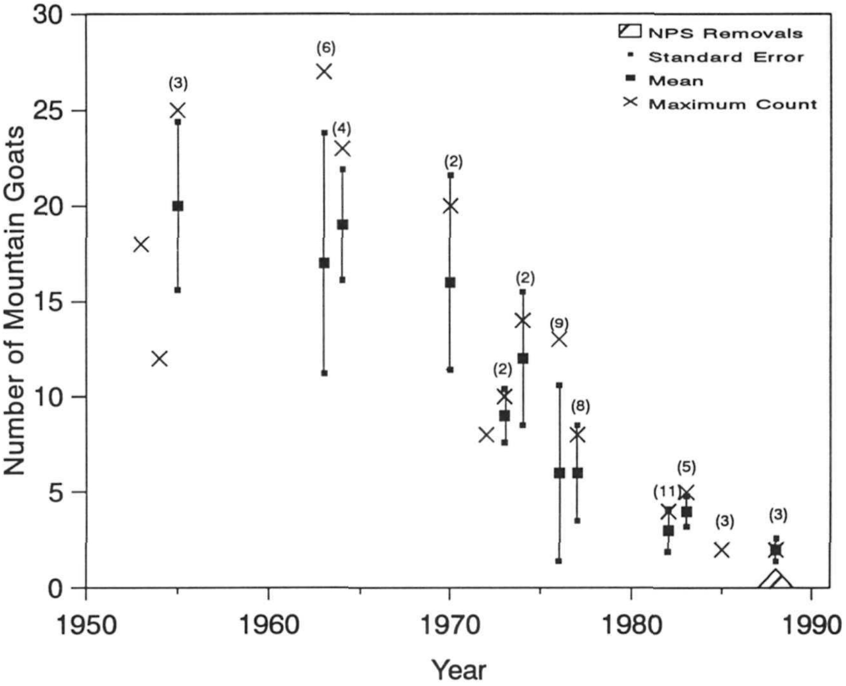


Fig. 20. Ground counts and National Park Service removals for Baldy Ridge–Hughes Creek mountain goats. Counts made during November–April periods; number of annual counts in parentheses.

It is likely that the decline in goats was real and that K_l declined as forest cover increased. The absence of kids in winter populations since 1982 also suggests a declining resource base.

Only one goat has been removed from the area by the National Park Service (Table 6). Goats have been hunted legally outside the park each year in this area since 1971, but removals averaged fewer than 1/year through 1983, and 1.5 ± 1.2 SD/year from 1984 to 1989 (R. Johnson, Washington Department of Wildlife, Olympia, personal communication, 1983; Washington Department of Wildlife 1982–90). Harvest likely contributed to the decline, but the timing and magnitude of change suggest that the decline was driven largely by changes in resource availability. The scenario described for the Baldy Ridge subpopulation, where fire and plant succession apparently played major roles, does not seem to be important in subpopulation trends elsewhere in the Olympics. Coincidental enhancement of this winter range by fire near the site of goat introduction, however, may have facilitated mountain goat establishment in the Olympics.

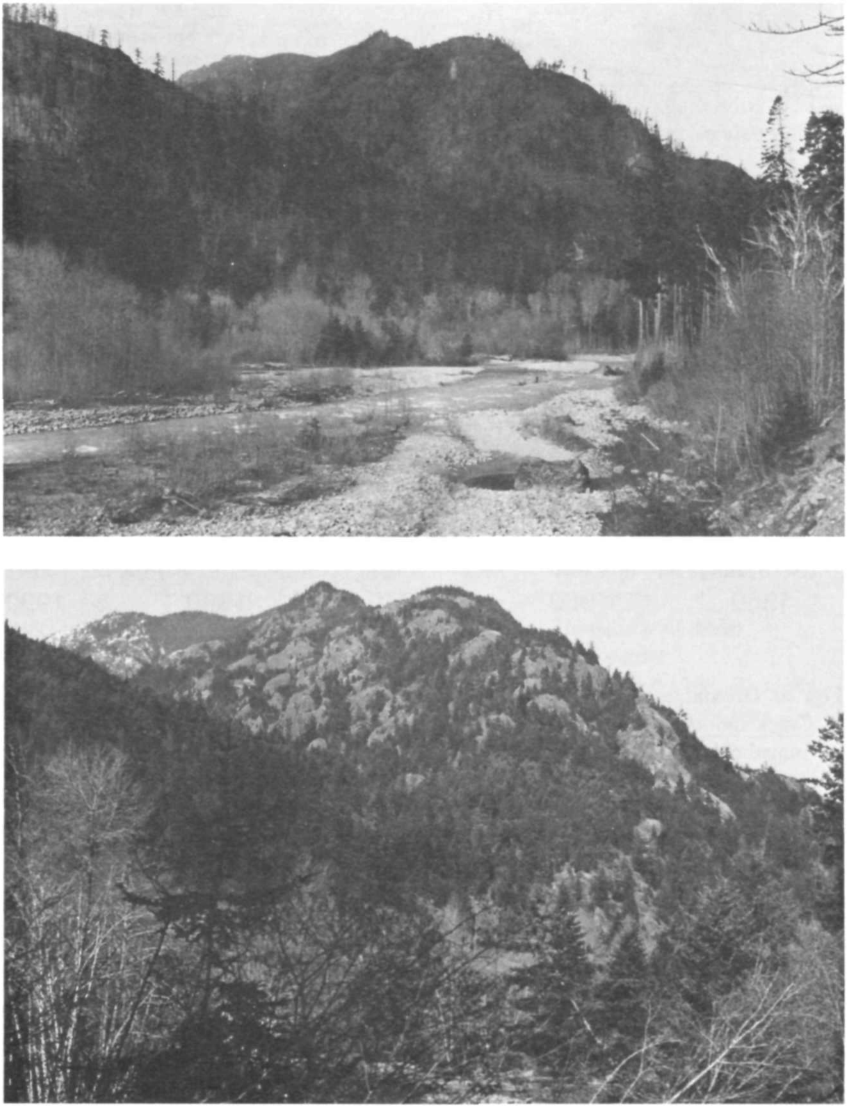


Fig. 21. Mount Baldy from the Elwha River on 10 March 1907 (*upper*) and 16 March 1983, showing early burn and the increase in forest cover during the intervening 76 years on the goat winter range. (Asahel Curtis collection, Washington State Historical Society; retake by E. G. Schreiner)

Mount Dana–Mount Wilder

This subpopulation was well established on the steep, east-facing escarpment of Mount Dana when we conducted our first helicopter count in 1983. The count of 45 animals was much higher than anticipated and added considerably to the standard error of the rangewide goat census (Houston et al. 1986). We know little about the seasonal distribution of these goats; occasional sightings suggest that they remained on the extensive east- and south-facing cliffs of Dana and Wilder throughout winter (R. W. Olson, personal observation).

Eight aerial counts were obtained from 1983 through 1990 (Table 7; Fig. 22). The subpopulation declined at $\bar{r} = -0.34$ as 39 goats were removed during 1985–89, including 25 taken in 1985. Only five to six animals were estimated to remain in 1990.

Mount Appleton

Goats were reported from the Mount Appleton area shortly after their introduction to the Olympics, and 12 censuses were available from 1979 to 1991 (Table 8; Fig. 23). Relocations of seven radio-instrumented females showed that the subpopulation was seasonally migratory and that some goats wintered on wooded cliffs along Cat, Schoeffel, and Boulder creeks.

Table 7. Mountain goat (*Oreamnos americanus*) numbers and removals, Mount Dana–Wilder, 1982–1990.

Year	Count[a]	Population estimate	Month	NPS removals	Source and comments
1982	12[b]		6		Hoffman[c]
1983	45	68[d]	7	4	
1984					
1985	18	27	8	25	Hoffman[e]
1986	6	9	7		Hoffman[e]
	10	15	8		Houston[f]
1987	20	30	6		Houston[f]
1988				7	
1989				7	
1990	3	5	7		Houston et al. 1991
	6[b]		7		Olson[g]

[a] All counts from helicopter except where otherwise noted.

[b] Count from fixed-wing aircraft.

[c] R. A. Hoffman, personal communication, 1991.

[d] Estimates produced using helicopter counts only, with observability of 0.66. Observability using fixed-wing counts is unknown but would certainly be lower than by helicopter in this area.

[e] R. A. Hoffman, Olympic National Park, unpublished data.

[f] D. B. Houston, Olympic National Park, unpublished data.

[g] R. W. Olson, Olympic National Park, unpublished data.

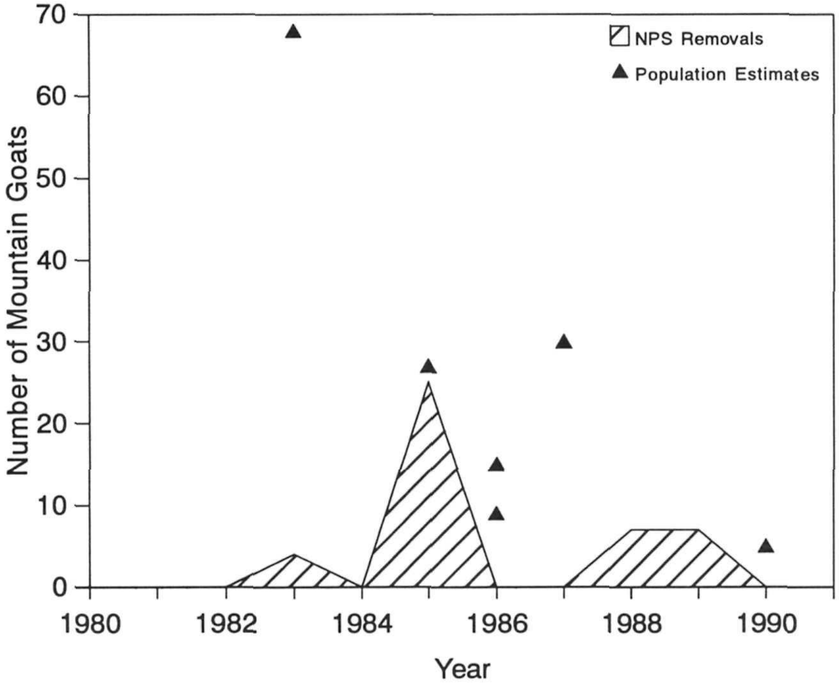


Fig. 22. Population estimates (from helicopter counts only) and National Park Service removals for the Mount Dana–Mount Wilder mountain goats.

Comparisons of ground and aerial counts were difficult, because aerial counts included a larger area. Steven's estimate of 35–50 goats in the subpopulation by 1980 was based on ground counts of the Mount Appleton–Cat Creek area (about 500 ha). Aerial counts covered about 1,082 ha that included Mount Appleton, High Divide, and Bogachiel Peak. Counts were adjusted using a sightability of 0.71 determined for the specific area (Hoffman 1987). Based on the helicopter counts, the population declined precipitously ($\bar{r} = -0.33$) until, by 1991, only three adult males were found in the area. The major decline seems to have occurred between 1983 and 1984, perhaps associated with the intervening winter. (We have no measure of winter severity from the area. Snow course records from Hurricane Ridge, 20 km distant, showed 198 cm and 145 cm of snow during April 1983 and 1984, considerably more than the 69 ± 25 cm mean of the previous 5 years.)

The role in the decline of human predation and an experimental sterilization program were examined. Eleven goats were removed from the area by the National Park Service from 1983 to 1988, including 9 in 1988. Hoffman (1987) attempted to sterilize seven females in the subpopulation (three in 1983, four in 1984). Although three of the females subsequently produced young, sterilization seemed to be partially effective in reducing reproduction by 1986 (Hoffman

Table 8. Mountain goat (*Oreamnos americanus*) numbers and removals, Mount Appleton, 1979–1991.

Year	Count[a]	Population estimate	Month	NPS removals	Source and comments
1979	30		7-8		Stevens[b]
1980	25	35–50	7-8		Stevens[c]
1981	42	42–45	7		Stevens[c]; Hoffman [d]
1982	20		7		Hoffman[d]
1983	46[e]	65	7	1	Houston et al. 1986
1984	21[e]		7	1	Houston[f]
1985	8[e]	12	7		Hoffman 1987
	13[e]	19	8		Hoffman 1987
1986	21[e]	30	6		Hoffman[g]
	17[e]	25	7		Hoffman 1987
1987	10[e]	15	6		Hoffman[d]
1988				9	
1989					
1990					
1991	3[e]	4	7		Houston[f]

[a] All counts were from ground except as otherwise noted. The 1979–80 ground counts were cumulative over summer and represent the minimum number of individuals present (V. Stevens, Olympic National Park, personal communication, 1991).

[b] V. Stevens, Olympic National Park, personal communication, 1991.

[c] V. Stevens, Olympic National Park, unpublished data, 1980.

[d] R. A. Hoffman, Olympic National Park, personal communication, 1991.

[e] Counts from helicopter. Helicopter estimates produced by using observability of 0.71 from Hoffman (1987).

[f] D. B. Houston, Olympic National Park, unpublished data.

[g] R. A. Hoffman, Olympic National Park, unpublished data.

and Wright 1990). Human predation and sterilization no doubt contributed to the overall decline, but the steepest drop from 1983 to 1984 was apparently environmentally driven because it occurred before intensive human intervention.

Sawtooth Ridge

Stevens (1980) documented the initial increase in this subpopulation at $\bar{r} = r_m = 0.23$ from 1977 to 1981 (Table 9; Fig. 24). Summer range for these goats straddled the eastern park boundary, and animals were thought to winter outside the park (Stevens 1980). Four counts from the 1985–90 period suggested relatively constant numbers. The National Park Service removed seven goats in 1989. The goats were hunted outside the park, but numbers removed cannot be determined for the subpopulation because the harvest was reported for a much larger management unit. Harvests from the larger unit from

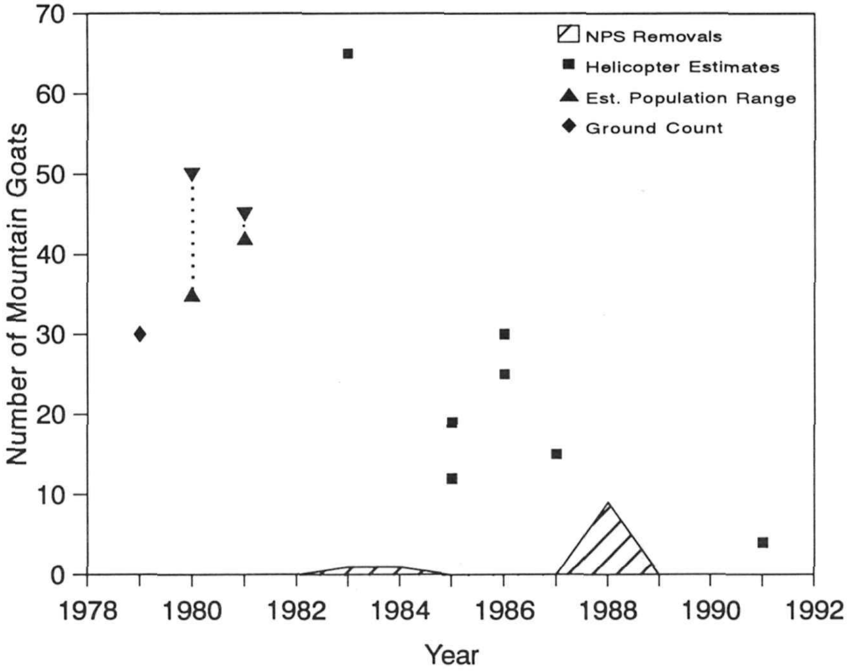


Fig. 23. Population estimates and National Park Service removals for Mount Appleton mountain goats. The ranges of population size for 1980 and 1981 were based on ground counts of a smaller area (see text).

1981 to 1989 averaged 3.9 ± 1.3 goats/year (Washington Department of Wildlife 1982–1990).

Mount Constance

The rugged terrain around Mount Constance and Charlia Lakes in the northeastern Olympic Mountains had been colonized by mountain goats by the 1940's. The area was impossible to census thoroughly from the ground, and the subpopulations during 1979–81 were estimated from ground counts at 60–120 goats (Table 10; Fig. 25). Two helicopter counts over the 3,546-ha area (a considerably larger area than covered by ground censuses; V. Stevens 1991, personal communication) suggested that a major decline in goat numbers occurred between 1983 and 1990—this was associated with the removal of 13 animals by the National Park Service. Animals were hunted outside the park, and known hunting removals averaged 6.2 ± 2.0 goats/year from the

Table 9. Mountain goat (*Oreamnos americanus*) numbers and removals, Sawtooth Ridge, 1977–1990.

Year	Count[a]	Population estimate	Month	NPS removals	Sources and comments
1977	5		7–8		Stevens[b]
1978					
1979	12		7–8		Stevens 1979
1980	14	17	7–8		Stevens 1980
1981	16		8		Hoffman[c]
1982	13		8		Hoffman[c]
1983					
1984					
1985	19		8		Seaman[d]
1986	16		7		Hoffman[c]
1987					
1988	20		8		Mills[e]
1989				7	
1990	11[f]	17[g]	8		Houston et al. 1991a

[a] All counts from the ground except where otherwise noted. The 1977–81 counts were cumulative over summer and represent minimum number of individuals present (V. Stevens, Olympic National Park, personal communication, 1991).
[b] V. Stevens, Olympic National Park, personal communication, 1991.
[c] R. A. Hoffman, Olympic National Park, personal communication, 1991.
[d] D. E. Seaman, unpublished data.
[e] L. S. Mills, personal communication.
[f] Counts from helicopter.
[g] Estimate for 1990 produced using observability of 0.66.

larger goat management unit from 1981 to 1989 (Washington Department of Wildlife 1982–1990).

Miscellaneous Subpopulations

We have limited information on trends and removals for four additional subpopulations from 1983 to 1990 (Table 11). The Chimney Peak subpopulation occupies the steep canyon walls along the upper Quinault River entirely within the park. We were dismayed to count 52 animals during the 1983 census, and this high count, like the one on Mount Dana, added substantially to the standard error of the rangewide census. Numbers apparently declined by 1990. The Royal Basin subpopulation intermingled with goats from Mount Constance and also ranged outside the park (Stevens 1980). The Royal Basin subpopulation had declined sharply by 1990. The Buckhorn subpopulation occurs outside the northeastern corner of the park, and the Pershing–Washington subpopulation is present outside the southeastern corner. Both subpopulations were hunted and seemed to have declined.

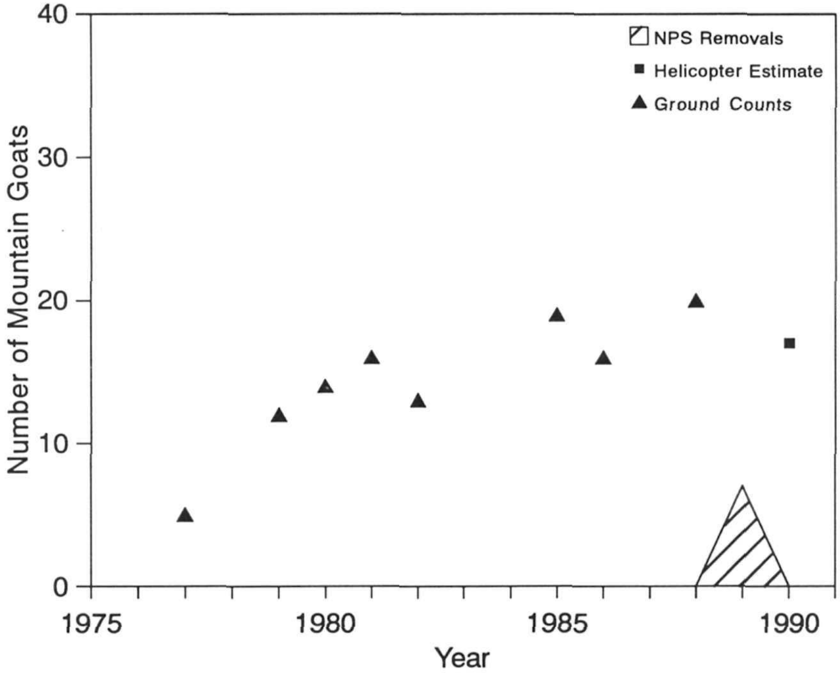


Fig. 24. Population estimates and National Park Service removals for Sawtooth Ridge mountain goats.

Interpretation

The review of dispersal, population trends, and the experimental manipulation of the KR animals provided insights into mountain goat ecology as well as information useful for park management. Mountain goats colonized the varied landscapes of the Olympic Mountains in about 60 years. Dispersal rates of around 3–6 km/year are comparable to those documented for mountain ungulates elsewhere (Caughley 1977). The pattern of subpopulation establishment was complex, patchy, and probably influenced locally by climatic events and by the presence of suitable winter range.

The possible influence of recent climatic events on colonization is notable. Initial colonization of the range coincided with the period of reduced precipitation (the 1920's through the 1940's), including the most prolonged spring–summer drought in 300 years (see Chapter 2). Occupancy of the Bailey Range began during the 1960's and could have been facilitated by the period of reduced winter snowpacks that have generally continued to the present. We do not know to what extent, if any, these climatic trends aided colonization, but subpopulations in the Bailey Range may not persist if high winter snowpacks return.

Table 10. Mountain goat (*Oreamnos americanus*) numbers and removals, Mount Constance area 1977–1990.

Year	Count[a]	Population estimate	Month	NPS removals	Source and comments
1977	18	40	6–8		Stevens[b]
1978	19	33	6–8		Stevens[b]
1979	22	59	7		Stevens[b]
1980	60	80–120	7		Stevens 1980
1981	?	60–80			Stevens 1983
1982					
1983	65[c]	99	7		Houston et al. 1986
1984–87					
1988				7	
1989				5	
1990	24[c]	36	7		Houston et al. 1991a

[a] All counts are from ground except where otherwise noted. The area covered by ground counts was inconsistent in size and was generally much smaller than the helicoptor count unit (see text).

[b] V. Stevens, Olympic National Park, personal communication, 1991.

[c] Count from helicopter. Helicopter estimates for 1983 and 1990 were produced using observability of 0.66.

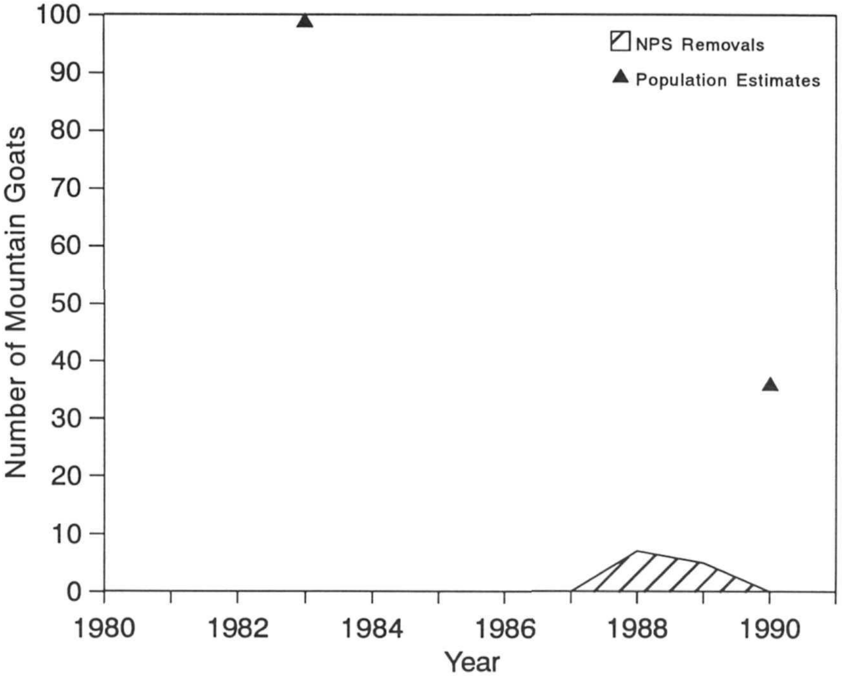


Fig. 25. Population estimates (from helicopter counts only) and National Park Service removals for Mount Constance mountain goats.

Table 11. Number of mountain goats (*Oreamnos americanus*) counted in four areas of the Olympic Range during July 1983 and 1990 censuses. Numbers are actual counts and were not adjusted for sightability.

Area	1983	1990	Goats removed 1984–90 by NPS
Chimney	52	35	12
Royal Basin	36	0	14
Buckhorn	33	11	
Pershing/Washington	13	8	

Body weight suggests that r_m for the mountain goat should approach 0.30 (Caughley and Krebs 1983). Several introduced goat populations have approached this rate (Houston and Stevens 1988), including the subpopulations on KR (0.24) and Sawtooth Ridge (0.23) in the Olympics. Rates of increase approaching r_m apparently do not persist for lengthy periods, as mountain goat populations may be especially sensitive to resource limitations (see Chapter 5).

Unfortunately, growth trajectories of the metapopulation and most subpopulations were not closely tracked, and we have incomplete records. The incomplete picture suggests quasi-independent subpopulations growing and declining asynchronously across the range, notwithstanding the recent rangewide decline. The pre-1986 variations in subpopulation sizes seemed driven by forces as varied as drought, winter severity, postfire plant succession, and levels of human predation. Striking differences in demographics of subpopulations and condition of individual goats underscore this diversity (Stevens 1983). Growth or decline of subpopulations at different rates across areas of small geographic scale may contribute to difficulties encountered elsewhere in managing mountain goat populations for sustained-yield harvests.

Trends in numbers of KR goats provided information useful for their management in the park and elsewhere. For example, a partial compensation model (PCM) and a harvestable surplus model (HSM) dominate ungulate harvest theory, although these competing models have not been adequately tested (Caughley 1976, 1985). Under the PCM, cropping to produce a sustained yield always reduces population density and maintains it below K_l. Under the HSM, hunting mortality and natural mortality are presumed to be compensatory, and the population is not reduced below K_l if it is cropped at a level equal to the production of young or yearlings (depending on the version of the model). Goat removals permitted a rough test of the HSM. If the HSM was appropriate, then the population should have declined at about $\bar{r} = -0.02$ to -0.03—the extent that cropping exceeded the number of young in the initial population (June and fall). An $\bar{r}$ of -0.12 should have occurred for the yearling cropping version. Instead, numbers plummeted at $\bar{r} = -0.40$. The HSM is clearly inappropriate for the KR goats. Removals drove the population below even a theoretical maximum sustained yield for the PCM at economic carrying capacity ($K_c = K_l/2$; Caughley 1976a). This would have been a disaster if sustained harvest had been the management goal. However, these results provided part of the framework for assessing goat management alternatives in the park (see Chapter 14).

It was difficult to assess the relative contributions of the National Park Service removal program and other forces to the decline in the metapopulation from 1983 to 1990. Exploratory regression using six park subpopulations (KR, Appleton, Royal Basin, Dana–Wilder, Constance, Chimney) showed a nonsignificant relation ($Y = -0.66x + 0.66$, $r^2 = 0.27$, $P > 0.10$) between the proportions of the 1983 subpopulations removed and the proportions of the initial populations remaining by 1990 (1991 for Appleton). Thus, either the effects of the removals were complex and variable among subpopulations, or the census precision was too low to measure the effects of removals at the subpopulation level. Further, some subpopulations declined without removals and others declined more precipitously than expected if removals were the primary agent of decline. (These unexpected declines might have reflected, in part, the effects of demographic dependence, where immigration from donor subpopulations maintained goat densities in recipient subpopulations. Reducing donor subpopulation sizes produced fewer dispersing goats, which contributed to declines in recipient subpopulations.)

Known goat removals from 1983 to 1990 were highly variable and averaged 46.6 ± 34.7 goats/year, only 4% of the estimated 1983 population. This seemingly low value may be misleading because additional mortality may have been associated with the National Park Service goat captures, and removals were not distributed across the metapopulation in relation to goat densities but were sometimes concentrated on particular subpopulations. In relation to additional mortalities, aerial darting and net gunning were used to capture goats from 1985 to 1989 (Houston et al. 1991b); only rarely were kids captured with these techniques during July (primarily) operations. About 66% of the 102 adult females captured were lactating, and we suspect that few of their kids survived (data on orphaned kid survival elsewhere are scant and contradictory; Foster and Rahs 1982). Moreover, some yearlings may continue to depend heavily on maternal females (Hutchins 1984). Consequently, the population effects of the National Park Service removals could have been greater than indicated.

In relation to subpopulations, National Park Service removals were probably the force driving the decline of the KR goats, but even there, goat numbers continued to decline when removals were discontinued from 1985 to 1987. Similarly, park removals probably contributed to substantial declines at Dana–Wilder and perhaps Royal Basin. Declines at Mount Appleton over the same period were likely due to winter mortality. Such patterns are not unusual for mountain goats. Smith (1984), for example, documented strong density-independent mortality among goat populations in southeastern Alaska during severe winters. Although National Park Service removals were a strong influence on the decline of certain subpopulations, the metapopulation decline between 1983 and 1990 was also influenced by environmental forces—most likely the return to winters with substantial snowpacks.

Caughley (1970a, 1976a) developed a model of ungulate population growth based on earlier work by Riney (1955). Under the Riney–Caughley model, "When ungulates are introduced into a previously unoccupied area they increase to a peak density and then crash steeply to a considerably lower level. Subsequent oscillations are heavily dampened and density finally steadies well below the initial peak. The vegetation follows a reciprocal trajectory..." (Caughley 1976a:197).

Our information on mountain goat subpopulation growth was too fragmentary to provide a test of this model. The pattern of colonization seemed to be complex, and we lacked reliable dates for the establishment of key subpopulations. The decline in the Baldy Ridge subpopulation (among the first established) was consistent with the model, but this was confounded by postfire plant succession. Several of the most recently established subpopulations seemed to be the fastest growing, their growth rates possibly accelerated by yearling breeding (see Chapter 5) as expected from the model, but most were also hunted. Mountain goats affected plant cover, but neat reciprocal relations between goats and vegetation density were difficult to discern across the Olympic Mountains because of the dissimilarities in plant communities (see Chapters 2 and 9–12) and the infrequent goat censuses.

Chapter 5. Demography

D. B. Houston, V. Stevens, and B. B. Moorhead

The demographics of mountain goat populations are poorly understood. Moreover, with a population already at equilibrium, little can be learned about either the density-dependent processes that produce a 0 rate of increase or the intensity of resource limitation. The most revealing studies involve natural experiments with growing populations (Caughley 1970a; Sinclair 1977; Bayliss 1985) or populations deliberately reduced from equilibrium. Accordingly, we examined changes in dynamics and physical condition of mountain goats resulting from the reduction in density of the Klahhane Ridge (KR) subpopulation (summarized from Houston and Stevens 1988). Additionally, the dynamics and condition of goats in the KR subpopulation are briefly compared to other subpopulations.

Subpopulations

Klahhane Ridge

Study of mountain goat dynamics from 1977 to 1981 showed differences in reproduction and condition between the subpopulation occurring at the highest density—KR—and eight others (Stevens 1983). The KR goats were considered to be strongly resource limited and were chosen for an experimental management program in 1981. Goats were removed annually during 1981–84 as an experiment to measure the response of the subpopulation to artificial reduction. This approach represented an unbalanced manipulative experiment (sensu Hurlbert 1984) because there was no appropriate subpopulation to serve as an unmanipulated control (possible candidates lacked comparable background information or occurred in dissimilar environments at densities that did not approach that of KR). If our hypothesis of resource limitation was correct, we expected increased reproduction, recruitment, and improved condition as density was lowered.

Census techniques were described in Chapter 4. Additionally, sex and age compositions were sampled in extensive ground surveys. Sexes and ages (kids, yearlings, and adults) of goats were determined by horn shape and size, body size, urination postures, and pelage, as described by Stevens (1983) and Hutchins (1984). Goats were captured from 25 June to 16 July 1981–84. Most were trapped under a 12- × 12-m drop net (Johnson and Moorhead 1982). Goats were weighed, and horn and body measurements were recorded. Age was estimated by horn rings and incisor replacement (Brandborg 1955; Stevens and

Houston 1989). Lactation status of each female was noted. Small numbers of goats were collected during periods in late winter—before and after the intensive trapping program—and subjected to necropsy (Houston and Stevens 1988).

Sex and Age Compositions

Twenty estimates of the sex and age compositions were obtained for birth-pulse and fall populations during 1976–86 (Table 12). Like all such surveys, these data contain sampling errors, which are especially crucial at low population levels. Adult males frequently occur singly or in small groups and may be underrepresented, especially during June (Stevens 1983). The percentage of adult males doubled, however, in the low-density populations of fall 1982–86 (36 ± 9.6% SD) compared with those of 1976–81 (18 ± 4.9%). These changes may have occurred in part because capture effort was sometimes directed at female–young groups (about 60% of all goats removed were female).

Production and Recruitment of Kids

The low to moderate precision of the population estimates (Houston and Stevens 1988) make it difficult to interpret the patterns in June production and subsequent fall recruitment of kids. Although we lack estimates for June kid:female ratios in 1976 and 1977, the September values were high (0.77 and 0.97, respectively; Table 12), and a partial count for 1976 suggests that goat numbers were relatively high (Table 5). If these September values are used also to represent June kids, then production by the high populations of 1976–81 was significantly more variable (CV = 47%) than for the lower populations of 1982–86 (CV = 12%; variance ratio test, $P < 0.05$; Zar 1984). Similarly, fall recruitment was more variable at the respective high populations (46%) than at low populations (16%). Differences in variation indicate that a greater proportion of females did not reproduce annually or rear kids successfully in the high density populations; they may have been more sensitive to either particularly favorable or poor environmental conditions than females in the low density population.

Production and recruitment of kids during 1978–86 seemed to be negatively associated with population size the previous year ($\hat{N}_{t-1}$ = fall or postremoval estimates). Exploratory linear regression analyses defined some of the variation observed. September kid ratios were significantly and negatively associated with $\hat{N}^2_{t-1}$ ($r^2 = 0.49$; $P < 0.05$). Similarly, the June ratios were significant at $P < 0.10$ but explained relatively little of the variation observed ($r^2 = 0.25$). Multiple regression models using estimates of the number of kids from June and September seemed to be negatively associated with population size and several indices of winter severity, but the relations were not significant ($r^2 = 0.35$–0.49; $P < 0.10$; Houston and Stevens 1988). Data sets were too limited to do little more than hint at the observed influences. They suggested, however, that relations between the production of kids and population size or environmental conditions were complex and perhaps nonlinear (Fig. 26).

Table 12. Sex and age compositions of Klahhane Ridge mountain goat (*Oreamnos americanus*) population, 1976–1986.

			Percent composition[a]						Number per 100 females					
Year	Month	*n*	F	Yg	YrF	YrM	TYr	AM	Yg	YrF	YrM	TYr	AM	Source
1976	September	113	42	33	5	4	9	16	77	13	8	21	38	Moorhead[b]
1977	September	110	35	34			17	14	97			50	42	Stevens 1983
1978	June	95	52	9			20	19	18			39	37	Stevens 1983
	September	119	50	13			22	15	27			44	31	
1979	June	89	44	26			13	17	59			31	38	Stevens 1983
	September	94	51	29			5	15	56			10	29	
1980	June	96	40	30			15	15	74			36	36	Stevens 1983
	October	83	42	24			12	22	57			29	51	
1981	June	129	37	12	10	13	23	28	33	27	35	62	75	R. Hoffman[c]
	October	116	41	11	12	10	22	26	27	29	23	52	63	
1982	June	95	43	24	5	6	11	22	57	11	14	25	53	Houston and Stevens1988
	October–December	48	44	21	2	2	4	31	48	5	5	10	71	
1983	June	79	43	23	9	6	15	19	53	21	15	36	44	Houston and Stevens 1988
	September	45	36	20	7	11	18	26	56	19	31	50	75	
1984	June	34	32	21	3	6	9	38	64	9	18	27	118	Houston and Stevens 1988
	September	27	37	22	4	7	11	30	60	10	20	30	80	
1985	June	21	29	14	5	5	10	47	50	17	17	34	167	Houston and Stevens 1988
	September–October	22	32	14	5	5	10	44	43	14	14	29	143	
1986	June	22	27	18	5	5	10	45	67	17	17	34	167	Houston and Stevens 1988
	September	21	28	19	0	5	5	48	67	17	17	167		

[a] F = female 2 years and older; Yg = young of the year; YrF = yearling female; YrM = yearling male; TYr = total yearlings; AM = males 2 years and older.

[b] B. Moorhead, Olympic National Park, unpublished report, 1976.

[c] R. Hoffman, Olympic National Park, unpublished data.

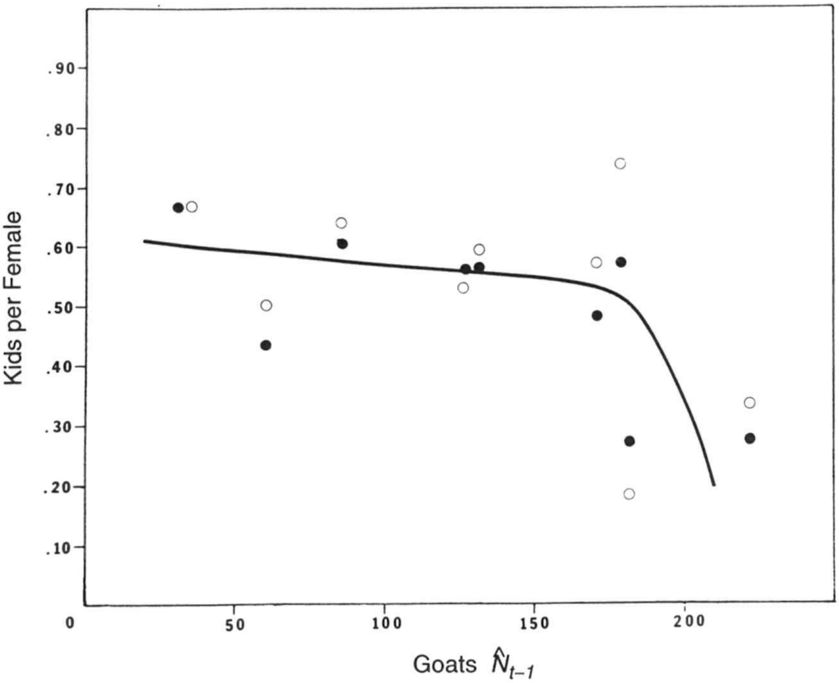


Fig. 26. The relation of June production (○) and fall recruitment (●) of mountain goat kids to population size on Klahhane Ridge, Olympic National Park. $\hat{N}_{t-1}$ represents fall populations from 1977 to 1980 and postremoval or summer estimates from 1981 to 1986. Line-fitted by eye.

Large mammals may show the nonlinear density dependence suggested in Fig. 26—that is, production or recruitment declines steeply as populations approach K_l (Fowler 1981a, 1987). However, we are only marginally comfortable with this interpretation for two reasons. First, sampling errors at low population size are of special concern (i.e., several females with kids overlooked in a survey profoundly alters the estimate). Second, as mentioned above, the 1976 and 1977 kid:female values were high and the goat population could also have been relatively high.

The best interpretation, considering the limited data, is that production and recruitment of goat kids are both more variable at high densities and may show some nonlinear density dependence. Variability in the production and recruitment of young is commonly greatest at K_1 for large mammals (Fowler 1987).

Initial Breeding Age

Field observations of tagged female goats with kids at heel (1981–84) provided a conservative index to age of initial breeding (Table 13). No yearlings or 2-year-old females were lactating or had kids at heel, indicating no successful

Table 13. Index to the age of sexual maturity of female mountain goats (*Oreamnos americanus*) on Klahhane Ridge as determined by kids at heel (1978–1980) and lactation records (1981–1984).

	Reproductive rate[a]			
Year	1 year old	2 years old	3 years old	4 years old
1978	0 (8)	0 (8)	0.33 (3)	0.29 (14)
1979	0 (1)	0 (10)	0.30 (10)	0.80 (5)
1980	0 (7)	0 (2)	0.30 (10)	0.70 (10)
1981	0 (4)	0 (10)	0.33 (3)	0.13 (8)
1982	0 (7)	0 (4)	0.00 (2)	0.75 (4)
1983	0 (6)	0 (2)	1.00 (2)	0.66 (3)
1984	0 (1)		1.00 (1)	1.00 (2)

[a] Proportion of females lactating or with kids at heel, indicating sexual maturity at $t - 1$; e.g., one of eight 4-year-old females was lactating in 1981, indicating sexual maturity (breeding) at 3 years of age. Sample sizes are given in parentheses.

breeding by kids or yearlings. By contrast, observations of individuals tagged as kids in colonizing subpopulations in the Olympic Mountains have shown that females are capable of breeding as yearlings (i.e., giving birth on their second birthday; Stevens 1980, 1983). Captive reared female and male goats will breed as yearlings (Houston et al. 1989).

Females generally became sexually mature as 2- or 3-year-olds in the established KR population. Although samples were small, reproduction of the 3- and 4-year-olds combined was greater at low densities (the proportion lactating or with kids at heel = 0.71, 1982–84) than at high densities (the proportion lactating or with kids at heel = 0.38, 1978–81; χ^2 test, $P < 0.05$). This suggested that initial breeding age declined (i.e., more 2- and 3-year-old females produced kids) when population density was reduced.

Litter Size

The observed proportion of births resulting in twins was low and variable from 1976 to 1986 (Table 14). Considerable care was taken to determine if females actually had twins at heel; this was aided by the high proportion of tagged females in the population. Rates were lower in the high-density populations ($\bar{x}$ twinning rate = 0.021 ± 0.028, 1976–81; χ^2 test, $P < 0.05$) than at low density ($\bar{x}$ twinning rate = 0.124 ± 0.164, 1982–86). The greatest number of twins (four sets) appeared in 1983. Twinning rates, although erratic, seemingly increased as density was reduced.

Individual Reproductive Histories

Reproductive performances of 24 tagged females, aged 3 years and older, were observed for 5 or more years (Table 15). Females were observed until removed from the KR subpopulation or until tags were lost. Only two tagged females remained by 1986. Overall production averaged 0.73 ± 0.262 kid per year, but there were striking differences among individuals (CV = 138%).

Table 14. Twinning rate for mountain goats (*Oreamnos americanus*), Klahhane Ridge, 1976–1986.

Year	Females with young	Sets of twins[a]	Twinning rate[b]
1976	36	1	0.028
1977	36	1	0.028
1978	9	0	0.0
1979	23	0	0.0
1980	29	0	0.0
1981	14	1	0.071
1982	21	2	0.095
1983	16	2[c]	0.125
1984	5	2	0.400
1985	3	0	0.0
1986	4	0	0.0

[a] June samples (except 1976 and 1977, for which only September minimum estimates are available).

[b] Proportion of observed births resulting in twins.

[c] Minimum estimate; four sets of twins known but only two were observed during the June survey.

Table 15. Production of young by 24 female mountain goats (*Oreamnos americanus*) aged 3 years and older, Klahhane Ridge, 1977–1986.[a]

Goat number	Initial age (years)	Year of observation/kids at heel 1	2	3	4	5	6	7	8	9	10	$\bar{x}$[b]
4Y	3	**1**	1	F	0	1						0.80
7Y	3	M	0	0	F	1	?	2				0.83
10Y	3	1	0	1	M	1	?	1				0.83
11Y	4	1	0	F	0	0	?	0				0.33
15Y	7	1	2	F	M	**1**						1.20
19Y	6	2	0	F	F	0						0.80
21Y	6	M	0	**M**	0	0						0.40
24Y	8	F	0	F	F	1						0.80
25Y	3	1	0	M	0	1	1	1				0.71
27Y	4	M	0	0	F	0	1	1	1	1	F	0.70
31Y	3	1	0	F	F	0	1	1				0.71
35Y	4	1	0	F	F	0						0.60
36Y	3	F	0	1	M	1	1					0.83
37Y	5	F	0	F	F	1	1	2	0			0.88
38Y	5	1	0	M	1	**1**	?	0				0.67
39Y	3	M	1	F	M	1	?	1				1.00
42Y	3	F	1	0	1	1						0.80
49Y	3	0	F	F	M	1	2	2	0			1.00
88Y	3	0	0	0	0	M						0.20
106Y	8	M	0	0	0	0						0.20
112Y	3	1	M	0	M	?	?	?	?	1		0.80
119Y	3	0	F	0	1	1	0					0.50
141Y	3	F	0	2	0	1						0.80
147Y	4	M	F	1	1	2						1.20

[a] M = male; F = female; sex of other kids undetermined. **Boldfaced** data indicate goat that died before reaching 1 year. All females first observed in 1977 except 49Y and 112Y (1978), 42Y, 119Y, 141Y, and 147Y (1979), and 88Y (1982).

[b] Average number of kids produced per year of observation.

Annual breeding plus occasional production of twins raised the mean annual production of two females to 1.20. By contrast, two other females produced only one kid each in 5 years (0.20). Bailey (1991) demonstrated similar wide differences in individual reproductive success for mountain goats in Colorado.

The sex ratio of the 42 kids surviving until midsummer was skewed—62M:100F (Table 15)—but the ratio did not differ from parity ($P > 0.05$). This small sample, however, hints that the predominance of adult females, which characterized the subpopulation at high densities (Table 12), could begin at an early age, with either differential production or, more likely, higher mortality of male kids.

Density-dependent Reproduction and Mortality

Additional density-dependent relations in the population were examined using *k*-factor analysis (Varley and Gradwell 1968), modified for vertebrates with overlapping generations (Southern 1970; Sinclair 1977). An earlier analysis of the 1977–80 populations showed that adult mortality plus dispersal were density-dependent (Stevens 1983). However, extended analysis suggested that only summer and winter kid mortality might have been density-dependent, but regressions of these *k*-factors on population size were not significant, and density dependence was not confirmed by this analysis.

Dispersal

Overall dispersal exceeded 10% for 130 tagged goats monitored in the high density KR subpopulations of 1977–81 (dispersal = one-way movement ≥15 km; Stevens 1983). Male dispersal (19.6%) during the 4 years exceeded female rates (5.5%), and dispersal of 1- to 3-year-olds (17.6%) exceeded rates of older goats (4.6%). Dispersal was not monitored during the 1981–84 population reductions. Clearly, dispersal was important in the dynamics of the KR goats at high densities.

Goat Condition

Live weights, measures of horn length, and fat deposits were evaluated as indices of goat condition. These samples seemed especially useful because they were acquired in a relatively brief period each year, 25 June to 16 July. Captured kids were about 3–6 weeks old and yearlings about 13 months. Lengths of right horns were measured on yearlings; lengths to first annuli (representing about 18 months of horn growth) were measured on 2-year-olds. Horn tip wear reduces lengths to first annuli in older animals (Stevens 1983); consequently, our analysis of horn growth is restricted to the two younger age classes.

1. Live weights were significantly and negatively associated with goat population size the previous year (i.e., fall or postremoval numbers, $\hat{N}_{t-1}$; Table 16). The relation was strongest for yearlings and 2-year-olds. Weights of the few adult males sampled showed no significant relations to density. Transformations of the variables did not significantly improve regression models.

Table 16. Relation between age-specific body weight and population size for mountain goats (*Oreamnos americanus*),[a] Klahhane Ridge, 1981–1984.

Goat	n	Slope	Intercept (kg)	r^2 [b]
Kids	28	–0.0325	18.3	0.15*
Male	11	—	—	NS
Female	17	—	—	NS
1 year old	36	–0.0993	50.0	0.50***
Male	20	–0.1204	54.1	0.56***
Female	16	–0.0760	46.1	0.37**
2 years old	25	–0.1102	63.6	0.39***
Male	10	–0.1121	66.4	0.46*
Female	15	–0.0806	56.1	0.23*
3 years old	19	–0.1156	75.4	0.28*
Male	11	—	—	NS
Female	8	—	—	NS
4+ Female	57	–0.0667	72.6	0.24**
5+ Male	10	—	—	NS

[a] Goats captured between 25 June and 16 July; population size = $\hat{N}_{t-1}$ (see text). Female goats reach adult body weight by 4 years of age, males by 5 years of age (Houston et al. 1989).

[b] Regression significance: * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$; NS = nonsignificant.

Annual samples were too small to examine effects of changes in density on the age-specific weights of lactating versus nonlactating females. However, four lactating 3-year-olds were heavier (61 ± 2.0 kg) than four nonlactating counterparts (43.3 ± 3.6 kg, $P < 0.01$) over the 1981–84 period. No differences were detected between lactating versus nonlactating females after adult weights were attained (4 years of age, $n = 17$, $P > 0.10$; ≥5 years of age, $n = 40$, $P > 0.10$).

2. Total horn length was significantly and negatively associated with population size for yearling males and for yearlings overall, but the variation explained by the model was low (Table 17). Yearling females and 2-year-olds showed no relations between horn length and population size. These results were not surprising because weight and horn length were only modestly correlated for yearling males ($r = 0.70$, $P < 0.001$, $n = 20$), yearling females ($r = 0.79$, $P < 0.001$, $n = 16$), and 2-year-old males ($r = 0.67$, $P < 0.05$, $n = 10$) but not for 2-year-old females ($r = 0.04$, $P > 0.10$, $n = 15$). Body weight is probably the more sensitive of the two indices and is less influenced by measurement error and extraneous variation including horn-tip wear.
3. Deposited fat reserves are measured commonly as indices to physiological condition in mammals. The sequence of fat mobilization for many ungulates is subcutaneous, perinephric, and finally, bone marrow (Hanks 1981). Fat deposits were measured on 13 mountain goats aged 2 years and older (Table 18). Although the sample is small, the cycle of accumulation and mobilization was generally as expected: the greatest deposits of perinephric

Table 17. Summary of the relations between horn length and population size for yearling and 2-year-old goats (*Oreamnos americanus*),[a] Klahhane Ridge, 1981–1984.

Goat	n	Slope	Intercept (cm)	r^2 [b]
1 year old	38	–0.0390	13.4	0.15*
Male	20	–0.0874	14.9	0.25*
Female	18	—	—	NS
2 years old	25	—	—	NS
Male	10	—	—	NS
Female	15	—	—	NS

[a] Goats captured between 25 June and 16 July; population size = $\hat{N}_{t-1}$. Total horn length measured in yearlings; length to first "annulus" in 2-year olds.

[b] * = $P < 0.05$; NS = nonsignificant.

and marrow fat were found during fall, and the lowest levels occurred in late winter or spring. Subcutaneous fat was absent, except in one goat. The kidney fat index was lower in the March–May 1981 sample (drawn from the high-density population) than for goats collected in 1985 (Wilcoxon's two-sample test, $P = 0.05$). Differences among marrow deposits were not significant. Differences in marrow fat would not be expected, even following large changes in density, because these deposits are the last reserves mobilized. Animals with depleted marrow are in poor condition, perhaps moribund (Mech and Delgiudice 1985). Changes in fat reserves from 1981 to 1985 generally support findings from the changes observed in body weights; goats were in better physiological condition at low population levels.

Other Subpopulations

Compared to KR, we know less about goat demography and condition in other subpopulations; interpretations are limited because density of these subpopulations was not manipulated deliberately. However, we compare the dynamics of KR goats to that of other subpopulations across the same years.

Stevens (1983) sampled the demography of nine subpopulations from 1977 to 1981. In addition to KR, these subpopulations included six that became established comparatively recently, were hunted outside the park, or both—Mount Constance, Mount Anderson, Sawtooth Ridge, Mount Elinor, Glacier Meadows, Bailey Range—plus the Mount Appleton and Royal Basin subpopulations within the park.

Production of kids was consistently greater for the combined subpopulations than for KR for 1977–81: 36 tagged females aged 3 years or older produced 0.93 ± 0.33 kid/female, whereas at KR, 58 females averaged 0.67 ± 0.30 kid. (Note: samples for individual subpopulations were small, and Stevens (1983) combined them to compare to KR). Moreover, greater proportions of 3- and

Table 18. Deposited fat reserves[a] in mountain goats (*Oreamnos americanus*) 2 years and older, Klahhane Ridge.

		Age	KFI	BMF	
Collection period	*n*[b]	Mean ± SD (range)	Mean ± SD (range)	Mean ± SD (range)	Sub Q
March–May 1981	7 (6)	4.0 ± 1.6 (2–7)	132.4 ± 14.9 (116–154)	68 ± 19.4 (29–83)	0.0
September 1981	1 (1)	7.5	232	91	1.0
October 1983	1	Ad[c]	373	93	0.0
March–May 1985	4 (2)	6.3 ± 3.5 (2–10)	159.7 ± 4.5 (155–164)	78.3 ± 16.9 (59–90)	0.0

[a] KFI = kidney fat index; BMF = percent bone marrow fat; Sub Q = depth (mm) of subcutaneous fat on rump.

[b] Number of females given in parentheses.

[c] Killed illegally, age undetermined.

4-year-old females had kids at heel in the combined subpopulations than at KR, suggesting that females were breeding at younger ages (Stevens 1983). The standing age distribution of captured goats showed that 57% of the KR females were age 5 or older versus 26% for the combined subpopulations, suggesting differences in recruitment, dispersal, or adult mortality. Dispersal rates for the combined areas were only 1.6% over 4 years—much lower than the 10% on KR. Moreover, age-specific comparisons indicated that females on KR tended to be smaller in stature and lighter in body weight than elsewhere (Stevens 1983). Reproductive rates remained high—0.77 and 0.67 kid/female in 1985 and 1986—for the combined Royal Basin, Sawtooth Ridge, and Constance subpopulations (Hoffman 1987).

These comparisons showed appreciable variation in demography and condition among subpopulations, suggesting that the intensity of resource limitation differed among the areas. Differences likely reflect (1) time since colonization, as some subpopulations may not have reached K_l (Bailey Range, Glacier Meadows, Sawtooths, Mount Elinor); (2) levels of hunting that mitigated resource limitation and maintained populations below K_l; (3) inherent differences in environment across the Olympic Mountains that resulted from precipitation gradients and vegetation differences; and (4) combinations of points 1–3. For example, goats in the environmentally harsh Bailey Range may have experienced frequent density-independent mortality and did not achieve equilibria, in any measurable sense, with their resources.

Metapopulation

Only two samples of reproductive rates obtained during rangewide censuses provided data on the metapopulation. Estimated ratios of kids to older animals were 0.217 ± 0.036 during July 1983 and 0.265 ± 0.041 during 1990 (from the air, yearlings and adult male and female goats could not be distinguished reliably), but reproductive rates did not differ between years (t-test for ratio estimators, $P > 0.05$; Cochran 1977).

Interpretation

The deliberate manipulation of the KR goats provided our still-limited insight into goat demography. The KR subpopulation showed density-dependent responses in initial breeding age and in litter size. Production and recruitment of kids were more variable at high densities. Changes in demography were associated with increases in live weights and fat reserves. Together, changes are consistent with those expected from a resource-limited population when the limitation is relaxed, resulting in this instance from reduced goat density. Considerations of mountain goat ecology suggest that the quantity and quality of winter food may be the limiting resource that determines ecological carrying capacity. Studies elsewhere have shown kid production to be negatively associated with winter severity during gestation (Adams and Bailey 1982; Swenson 1985; Bailey 1991).

Irrespective of age, female goats seemingly must reach a threshold fall body weight of about 70 kg before achieving sexual maturity (Houston et al. 1989). The changes recorded in weights and population dynamics at KR suggested that more young goats reached this threshold at the reduced population densities and also that adult females achieved the requisite condition more consistently.

Potentially, low kid production could result from females failing to breed, from fetal mortality, or from mortality of neonates. A small sample of females provided information on these possible sources of reproductive failure. Only one of six females 4+ years of age, collected during winter from 1981 to 1985 on KR, was pregnant. The reproductive tracts from the nonpregnant females did not show regressing corpora lutea, uterine scars, or distended uteri that would suggest recent fetal mortality. Thus, low production of kids in some goat populations may result from failure to breed or conceive because females did not achieve condition, rather than from mortality in utero or postpartum.

The differences in reproductive performance among individual females could result from inherited traits, social status, lifelong effects from birth-year environmental conditions, or some combination (Bailey 1991). Consistent dominance relations were observed among adult females on KR, but data were insufficient to establish an association with reproductive success in the particular females monitored (M. Hutchins, American Zoo and Aquarium Association, Bethesda, Maryland, personal communication, 1987). Among social mammals in general, dominant females often show superior breeding success (Clutton-Brock and Albon 1985).

Slopes of the density-dependent responses in kid production and recruitment remain obscure. Populations of large mammals may show the strongest density dependence near K_l (i.e., density dependence is nonlinear; Fowler 1981a, 1981b, 1987). If studies elsewhere confirm the suggestion that these relations are nonlinear in the mountain goat, then the seemingly enigmatic responses of some populations to harvest (i.e., the apparent absence of compensatory reproduction or survival; Kuck 1977) may be deciphered. Populations showing nonlinear density dependence should be most productive at densities just below K_l; density dependence may be difficult to detect if such populations are reduced by harvest substantially below K_l (Fowler 1981a).

Mountain goats—and mountain ungulates (sensu Schroder 1985) in general—may be especially sensitive to resource limitations; body growth, age of sexual maturity, and litter size may change sharply near K_l. Long-established mountain goat populations sometimes do not show marked density dependence (Hebert and Turnbull 1977; Kuck 1977). This suggests that the goat-induced changes in plant species composition and cover at K_l may not be quickly reversed by reducing the goat density (Adams and Bailey 1982). The time lag in response may exceed the length of most studies. This suggestion is speculative, and vegetation on the KR summer range changed measurably in response to reduced goat densities (see Chapter 10), but alpine plant communities elsewhere may require decades or longer to recover from just the nonconsumptive uses of humans (e.g., Willard and Marr 1970, 1971; Bell and Bliss 1973).

Chapter 6. Habitat Relations, Social Behavior, and Physiological Ecology

D. B. Houston, V. Stevens, and E. G. Schreiner

Habitat Relations

Habitat Utilization

The "psychological bondage" of mountain goats to cliffs and rock outcrops is well known (Brandborg 1955; Geist 1971; Chadwick 1983; Fox 1983; Hutchins and Geist 1987; Fox et al. 1989). Goats are apparently more strongly associated with cliffs than even bighorn sheep (*Ovis canadensis*; Geist 1971). The ability of goats to occupy and negotiate seemingly impossible terrain in the Olympic Mountains was a wonder to those of us involved in research and management.

Many goats in the Olympic Mountains are seasonally migratory; summer ranges are mostly above 1,520 m and consist of open subalpine and alpine meadows. We know more about habitat utilization by goats during summer than in winter.

Stevens (1979) sampled habitat use by the KR goats from 24 June to 4 September 1978 by recording 5,589 observations of up to 84 individually tagged animals. Bedding (42%) and feeding (40%) composed the activities most observed. Most (55%) of the feeding observations occurred in subalpine meadows (especially *Phlox*–fescue communities as described by Pfitsch and Bliss 1985; Fig. 27). Observations of feeding (38%) in sparsely vegetated rock-dominated sites (i.e., talus, scree, outcrops—which support *Phacelia–Cirsium* and *Phacelia–Achillea* communities) were second. Coniferous forest (7%) was third. South slopes were preferred foraging sites, but goats shifted feeding activity to cooler north slopes during warm days. Goats selected rock-dominated terrain—particularly cliffs—for bedding in 37% of the observations, followed by snowbanks (24%), bare ground (21%), and meadows (14%). Goats favored north slopes for bedding.

Intensive use of selected sites led to numerous conspicuous beds and wallows in subalpine and alpine areas. Often it was not possible to distinguish between a bed or wallow at many of these sites. Continued use eliminated vegetation at the site, modified the composition of adjacent vegetation (Reid 1983), and accelerated erosion on particularly steep slopes. Goats maintained site instability by throwing loose soil on themselves while wallowing. Wallowing may aid grooming, may provide thermoregulatory relief (when soils are damp), and may provide relief from biting insects (Brandborg 1955;

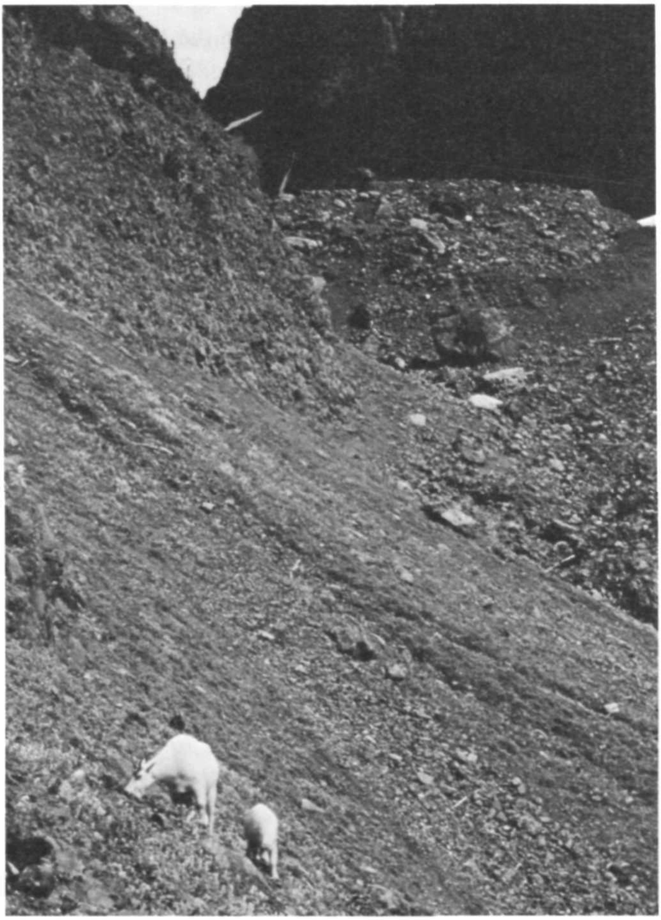


Fig. 27. Mountain goats foraging in Avalanche Canyon, Olympic National Park, August 1989. The sparse vegetation is typical of subalpine sites in the dry northeastern Olympic Mountains. Copyright J. E. Burger.

Stevens 1979). On Klahhane Ridge, goat wallowing occurred throughout summer—often during the warmest time of day (Stevens 1979).

Plots used to describe plant communities and document the extent of herbivory on summer ranges also provided perspective on goat habitat use. Evidence of goat activity (tracks, wallows, droppings) was extensive throughout the 22 areas surveyed in the park and was present in 15 of the 16 community types described, indicating the ability of goats to use a wide variety of plant communities. Pfitsch and Bliss (1985) noted that several herbaceous communities on KR were most heavily grazed when located near cliffs. These observations tended to confirm the strong association of goats with rocks and the seemingly overwhelming influence of these predilections on patterns of vegetation use.

The general locations of winter ranges for four subpopulations were reported from field observations (KR) and from telemetry of 18 radio-instrumented goats (KR, Royal Basin, Constance, Sawtooth Ridge; Stevens 1979). Goats wintered on steep south and southeast slopes below 1,500 m. Radio locations made from fixed-wing aircraft, however, were usually too inaccurate to pinpoint the actual habitat occupied (V. Stevens, personal observation). Fifteen relocations of 11 radio-instrumented goats made by helicopter during winter–spring 1985 in the Mount Appleton area (National Park Service, R. Hoffman, unpublished) showed that 90% of the sites occupied were coniferous forest on steep rocky southeastern or south-facing slopes between 1,200 and 1,500 m. Spring observations from the ground on KR, Baldy Ridge, and Mount Appleton typically showed heavy utilization of virtually all vegetation (including conifers) on cliffs and rock outcrops used during winter; these conditions extended 20–30 m from the cliffs into adjacent forests (D. Houston and R. Hoffman, personal observation; Fig. 28).

The duration of goat occupancy of seasonal ranges varied considerably among years in the Olympic Mountains. Summer ranges were accessible to mountain goats for longer than usual periods during several years in the 1980's because of low fall snowfall, and goats were able to occupy summer

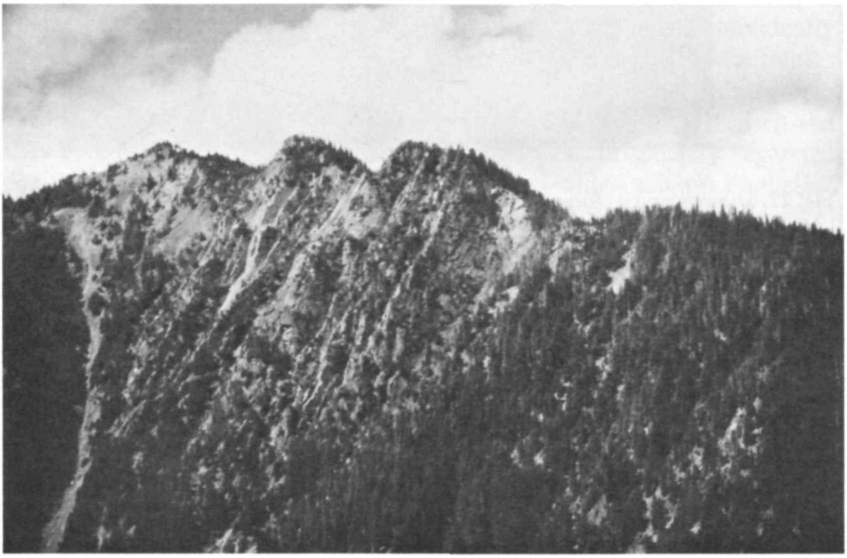


Fig. 28. A steep, forested southeast-facing slope that provided winter range for mountain goats in the Cat Creek–Schoeffel Creek area of Olympic National Park. (Photo by R. Hoffman, 2 August 1984)

ranges earlier in the year because of low snowpacks. On 16 January 1981, we (Houston and V. Stevens) obtained goat composition counts atop Hurricane Ridge under near-summerlike conditions. During typical winters, snow would have displaced goats from these high-elevation meadows. Crude indices to this variability are represented by the coefficients of variation for the January (46.7%, 1960–92) and April (51.8%, 1958–92) snow-depth measurements at Hurricane Ridge. Snow depths ranged from 18 to 234 cm in January and from 0 to 277 cm in April.

Studies of habitat selection by goats in coastal areas of British Columbia and southeastern Alaska have shown extensive winter use of coniferous forest on and adjacent to steep south slopes and cliffs (Hebert and Turnbull 1977; Schoen and Kirchoff 1981; Fox 1983; Smith 1984, 1986; Fox et al. 1989). Overstory trees in mature coniferous forests intercept snow and provide foraging sites that would be unavailable otherwise (National Council of the Paper Industry for Air and Stream Improvement 1989). Our limited observations suggest that goats use forests on winter ranges throughout the Olympic Mountains.

Goat Diets

Seasonal Diets

Seasonal diets of the KR subpopulation were examined to aid interpretation of the effects of goats on vegetation. Microhistological examination of fecal material was used to identify plant taxa in the diets (Vavra and Holechek 1980; Leslie et al. 1983).[9]

Of the nearly 200 plant species known on KR, 39 taxa were identified in seasonal diets (Table 19). Seven taxa made up at least 5% of the diets for one or more seasonal periods (Fig. 29).

Seasonal changes of forage classes in the diet were similar for goats elsewhere and for other medium-sized ungulates in mountainous areas of the North Temperate Zone. Grasses and grasslike plants composed about 60% of June–November diets; three forb species contributed much of the remainder. Shrubs and conifers predominated during winter. At the species level, *Phlox diffusa*, *Taxus brevifolia*, *Berberis nervosa*, and miscellaneous shrubs (mainly *Pachistima myrsinites* and *Vaccinium* spp.) were important components of the winter diet. *Festuca idahoensis* and *Carex* spp. dominated summer–fall diets. Miscellaneous species included

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[9] Analyses were performed at the Eastern Oregon Agricultural Research Station, Union, Oregon. Composite samples (5 g from each pellet group) were made for six seasonal periods from a sample of 245 pellet groups collected October 1977–April 1982 (January–March, 29 pellet groups; April–May, 25; June, 41; July, 39; August–September, 61; October–December, 50). Samples from fall 1977 to winter 1981 were collected by V. Stevens.

Table 19. Plant taxa identified in mountain goat (*Oreamnos americanus*) diets from Klahhane Ridge.[a]

Forage class	Scientific name	Common name
Grasses and grasslike plants		
	Agrostis variabilis	Mountain bentgrass
	Bromus sitchensis	Alaska brome
	Carex spp.	Sedges
	Dactylis glomerata	Orchardgrass
	Elymus glaucus[b]	Blue wildrye
	Festuca idahoensis	Idaho fescue
	Festuca ovina	Sheep fescue
	Juncus spp.	Rushes
	Luzula spp.	Woodrush
	Phleum alpinum[b]	Alpine timothy
	Poa spp.	Bluegrasses
	Sitanion hystrix	Squirreltail
	Stipa occidentalis	Western needlegrass
Forbs		
	Achillea millefolium	Yarrow
	Arabis spp.	Rockcress
	Campanula piperi	Piper's bellflower
	Cheilanthes gracillima[b]	Lace lip-fern
	Phlox diffusa	Spreading phlox
	Polystichum munitum	Swordfern
	Pteridium aquilinum[b]	Bracken
	Rubus spp.	Brambles
Browse		
	Acer circinatum[b]	Vine maple
	Alnus rubra[b]	Red alder
	Arbutus menziesii	Pacific madrone
	Berberis nervosa	Oregon grape
	Douglasia laevigata	Smooth douglasia
	Gaultheria shallon[b]	Salal
	Pachistima myrsinites	Oregon boxwood
	Symphoricarpos mollis[b]	Snowberry
	Vaccinium membranaceum[b]	Thin-leafed huckleberry
	Vaccinium parvifolium	Red huckleberry
Conifers		
	Abies lasiocarpa	Subalpine fir
	Pinus monticola	Western white pine
	Pseudotsuga menziesii	Douglas-fir
	Taxus brevifolia	Pacific yew
	Thuja plicata	Western redcedar
	Tsuga heterophylla	Western hemlock
	Tsuga mertensiana	Mountain hemlock

Table 19. *Continued.*

Forage class	Scientific name	Common name
Miscellaneous		
	Bryophytes	Mosses

[a] Taxa identified in 245 fecal pellet samples from goats collected during late winter or spring unless otherwise noted.

[b] Taxa identified in 9 rumen samples from goats collected during late winter or spring.

small amounts of six forbs in summer and *Polystichum munitum* (4.5%) and mosses (2.4%) in winter.

Only one of eight endemic plant taxa known on KR was recorded in the mountain goat diet. *Campanula piperi* made up 0.4% of the diet from January to March and 0.6% from August to September. Three other endemics—*Senecio neowebsteri*, *Astragalus australis* var. *olympicus*, and *Aster paucicapitatus*—were known to be grazed by goats (see Chapter 12; Pike 1981). Thus, the endemic

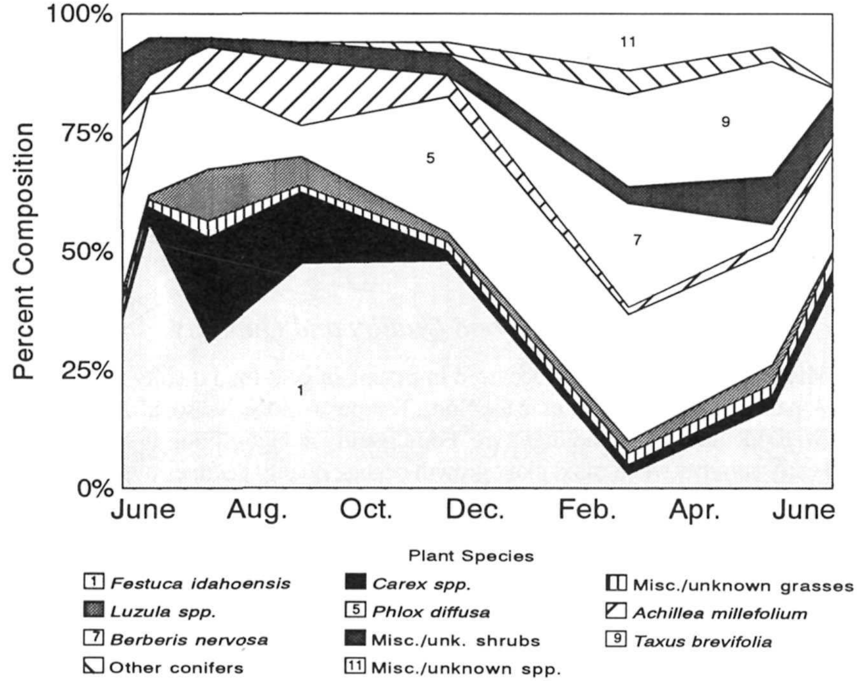

Fig. 29. Seasonal diets of mountain goats from Klahhane Ridge as determined from analysis of 245 pellet group samples. Plant species making up at least 5% of the diets during one or more seasonal periods are identified.

plants were so uncommon that they seemed to represent only incidental items in the diet of mountain goats.

We add several caveats to the interpretation of data on mountain goat diets. Although samples were corrected for differential digestibility of species (Leslie et al. 1983), microhistological analyses still provided only approximate diet composition. For example, forbs are highly digestible and consequently are often underestimated (Vavra et al. 1978; Samuel and Howard 1983). Field observations and indices of summer grazing on the KR vegetation plots (Pfitsch and Bliss 1985) showed widespread use by goats of many forbs that were present at low densities, and yet few of these were detected by fecal analyses. Parkwide, we expect great variation in the plant species consumed by goats—*Festuca idahoensis*, for example, is uncommon on ranges in the interior of the park. Considerations of the vegetation parkwide suggested, however, that the relative importance of forage classes would be general, even though the particular species in diets differed among subpopulations.

Finally, samples used in this analysis were collected during unusually mild winters when precipitation was below normal. High-elevation meadows were unusually available to wintering goats. In years with normal to heavy snow accumulations, diets dominated by the shrubs and conifers characteristic of January to March would probably also typify the October to December period.

The plant community survey plots provided additional insight into summer goat diets parkwide. Many different plant species were consumed in areas of high goat density,[10] although the particular species selected differed markedly among sites (see Chapter 9). These observations provided additional confirmation that goats in the Olympic Mountains were generalist herbivores and indicated that requirements for rocky habitats apparently overrode needs for particular forage species.

Seasonality of Food Quality and Quantity

Marked seasonal variation occurred in mountain goat food quality and quantity—parallel to most ungulates in the North Temperate Zone. Seasonal differences are well documented in the literature. Food quality is highest during late spring and early summer when rapid plant growth occurs; quality declines over summer and fall as vegetation matures; quality is lowest during winter when plants are dormant. Changes in food quantity generally lag behind food quality. Quantity is greatest in middle to late summer. Quantity is most limited during winter when goat distribution is constrained by snow accumulation and the animals feed on a fixed, less diverse, and declining resource base of dormant plants.

Definitions of food quality vary, but the concentration of nitrogen, reported as percent crude protein, is a useful index for ungulate foods if used cautiously

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[10] Plants were assumed to be eaten mainly by goats but included grazing by other mammalian herbivores as well.

(Crampton and Harris 1969; Cowan et al. 1970; Sinclair 1977). Seasonal crude protein concentration of seven plant species important in diets of KR goats showed that highest levels (around 15–20%) usually occurred during May–June and lowest levels (3–7%) during winter (Fig. 30).

Seasonal changes in the quality of goat diets, as indicated by crude protein values in forage, also were reflected in fecal nitrogen (N) levels. Fecal N averaged 1.69 ± 0.26% on KR during October to March 1977–81 and was 2.29 ± 0.41% for June samples (Stevens 1983).[11] Fecal N values from goats on three other summer ranges in the park (Mount Constance, Mount Appleton, and Royal Basin) averaged 3.27 ± 0.22% during 1980 and were greater than values from KR (Stevens 1983). Data on demography and goat condition led Stevens (1983) to conclude that these

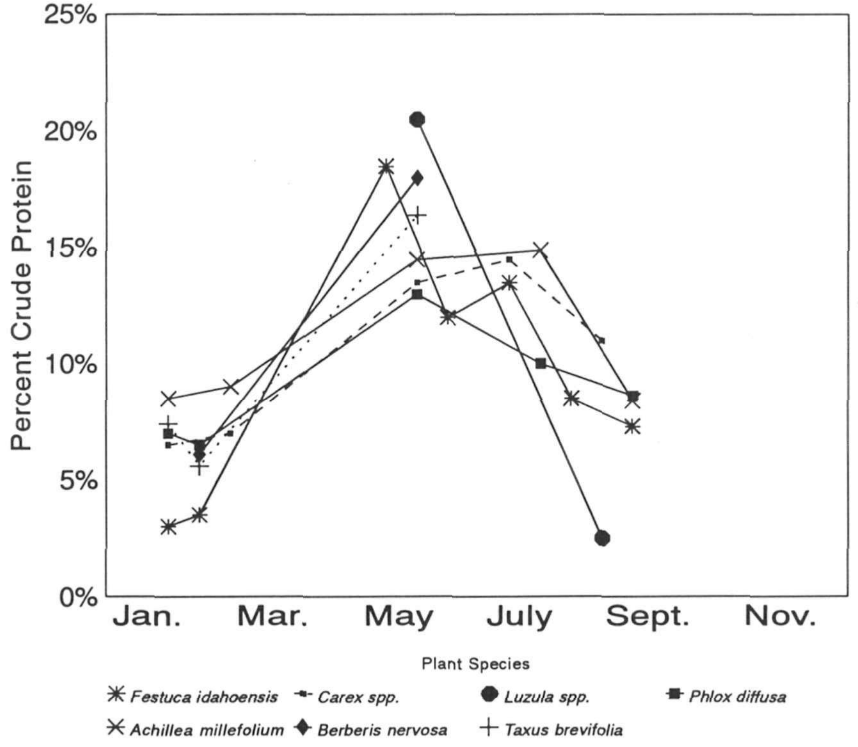

Fig. 30. Crude protein levels in seasonally important foods of mountain goats on Klahhane Ridge. Crude protein calculated as percent nitrogen × 6.25.

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[11] There is controversy over the validity of fecal N as an index of diet quality because tannins in some dicotyledonous forages may reduce protein digestibility (Hobbs 1987; Leslie and Starkey 1987; Robbins et al. 1987; Irwin et al. 1993). Here, values are used to reflect only broad seasonal differences in diet.

three subpopulations were less intensely resource-limited than goats on KR, and this was reflected in the fecal N values.

Measures of available food quantity are limited. Standing crop for nine major plant communities on 125 ha of summer range above 1,400 m on KR was calculated at 154,610 kg (~1,237 kg/ha) during 1979 (Pfitsch and Bliss 1985). Goats consumed a small proportion of the standing crop.

Diets Elsewhere

About 20 studies reported diets of mountain goats over the past 40 years. Differences in design and sampling methods, however, limit comparisons. Information on diets has been derived from rumen samples, range surveys that attempted to relate plant abundance to goat utilization, timed observations of feeding animals, examinations of feeding sites, and more recently, microhistological examination of fecal samples. All techniques are prone to sampling errors and biases (e.g., Nelson and Leege 1982).

Even with the limitations, several generalizations on food habits are useful:

1. Over their geographic range, goats consume a remarkable variety of plant species, including mosses, lichens, ferns, grasses, sedges, rushes, forbs, and a host of coniferous, deciduous, and evergreen trees and shrubs;
2. Spring and summer diets are usually dominated by grasses or forbs;
3. Winter diets are frequently dominated by browse species, including conifers;
4. The proportions of browse in diets increase sharply during severe winters; and
5. Conifers are often important components of winter diets, even during mild conditions when alternate forages are seemingly available.

These interpretations are drawn from our studies and from Casebeer et al. (1950), Brandborg (1955), Saunders (1955), Hibbs (1967), Geist (1971), Hjeljord (1973), Kuck (1973), Johnson et al. (1978), Thompson (1980), Adams and Bailey (1983), Campbell and Johnson (1983), Smith (1986), Fox and Smith (1988), Fox et al. (1989), and Cowan (I. M. Cowan, Wildlife Service, Department of Mines and Resources, Ottawa, Canada, unpublished report, 1944).

Mountain goats have anatomical specializations usually associated with ungulates that forage selectively—they possess relatively narrow muzzles and incisors (Janis and Ehrhardt 1988). Thus, in addition to their ability to consume many species, foraging goats frequently select specific, highly nutritious plant parts—particularly flowers, seed heads, and growing leaves or leaf blades (Saunders 1955; Hjeljord 1973; Olmsted 1979; Thompson 1980; Dailey et al. 1984). Moreover, wintering goats dig up and consume energy-rich, belowground plant structures, including fern rhizomes, roots of perennial forbs, bulbs, and tubers (Hjeljord 1973; Chadwick 1983; D. B. Houston, personal observation).

Social Behavior

Mountain goat society is matrifocal, with groups of females, kids, and young males generally living apart from groups of adult males, except during rut (Geist 1964; DeBock 1970; Chadwick 1977). Rut occurs from late November to early December, with large, dominant males doing much of the breeding (Brandborg 1955; Geist 1964; Hoffman 1987; Chadwick 1973). Male–male dominance is established by threat displays; fighting is apparently uncommon but can be deadly (Geist 1967; DeBock 1970; Dane 1977). Males tend individual females, as tending pairs, during the latter's 48-h period of sexual receptivity (Hutchins et al. 1987). Recurrent estrus may follow at intervals of about 20 days. Gestation is about 186 days, and females give birth in late May. Females remain in seclusion for up to 17 days postpartum as maternal–young bonds develop (Hutchins et al. 1987). Neonates are precocial followers (as opposed to hiders; Lent 1974) capable of negotiating difficult terrain after just a few days. Goat kids, as followers, grow initially more slowly than mule deer fawns (hiders; Carl and Robbins 1988). Kids nurse frequently but consume relatively less milk per nursing bout than do deer fawns.

Social Organization and Group Size

Goat society is ordered along dominance hierarchies, with dominant individuals frequently being older and larger (DeBock 1970; Chadwick 1977; Risenhoover and Bailey 1985). In the Olympic Mountains and in several other locations, large adult males seem to be dominant over females (Rideout 1974; Dane 1977; Stevens 1983); however, the extent and circumstances of male dominance may vary among populations (Geist 1964; De Bock 1970; Chadwick 1977, 1983; Masteller and Bailey 1988). Overt aggressive behavior toward social subordinates increases in winter when resources are limited (Petocz 1973). Conversely, agonistic behavior between goats apparently declines with increasing group size in summer when resources are abundant (Risenhoover and Bailey 1985).

Females that do not give birth may retain their yearling or even 2-year-old offspring at heel. Those with retained offspring, plus females with kids of the year, represent the nuclei of nursery groups (Hutchins 1984). Although associations among adults in nursery groups were not measured quantitatively in Olympic National Park, group constancy seemed to be low (Stevens and Driver 1978; M. Hutchins, American Zoo and Aquarium Association, Bethesda, Maryland, personal communication, 1988). In Glacier National Park, associations between tagged female goats also were low (Singer and Doherty 1985).

Mean group size for goats on summer ranges in the Olympic Mountains was 2.74 ± 3.51 SD (range 1–32, $n = 162$ groups) in July 1983 and 2.05 ± 1.80 (range 1–12, $n = 84$ groups) in 1990 and did not differ between years

(Mann–Whitney, $P > 0.05$). In 1983, 42 nursery groups (i.e., those containing at least one female with kid-at-heel) were larger and averaged 5.5 ± 5.46 goats; in 1990, 25 nursery groups averaged 3.8 ± 2.42 goats.

We recorded goat density and group sizes on KR during June censuses from 1981 to 1986 (Table 20). Mean group size was positively associated with June population size ($r^2 = 0.88$, $P < 0.05$) and declined precipitously during the goat reductions. Nursery groups showed similar changes; the largest such group recorded each year for 1981–86 was 31, 24, 33, 7, 6, and 6. The larger nursery groups (20 or more) often occurred in open meadows some distance from escape terrain. Risenhoover and Bailey (1985) suggested that large groups permit more efficient foraging in open terrain because individual females could devote more time to foraging and less time to alert behavior.

Limited November-to-March observations on KR suggested that winter groups were at least as small as in summer. Mean winter group size was 1.8 ± 2.21 goats (range 1–7, $n = 31$ groups).

Land Tenure and Home Range

Mountain goats in the Olympic Mountains showed fidelity to well established seasonal home ranges. One hundred twenty-five goats tagged on KR were reobserved for 2 or more years following capture. About 84% showed fidelity to summer ranges—several for 5–10 years (calculated from Stevens [1980, 1983] and subsequent National Park Service observations). Fifty-five of 57 tagged goats (97%) in 8 other subpopulations showed fidelity to summer ranges. Levels of fidelity to winter ranges were unknown but were probably similarly high because habitat was more limited and resources were in short supply. Goats elsewhere showed fidelity to summer (Rideout 1977; Thompson 1980) and winter ranges (Smith 1976; Kuck 1977; Schoen and Kirchoff 1981; Smith and Raedeke 1982); fidelity to winter ranges seemed

Table 20. Mountain goat (*Oreamnos americanus*) density and group size, Klahhane Ridge, 1981–1986.[a]

		Group size		
Year	Goats/ha	n	$\bar{x}$	CV[b]
1981	0.077	35	4.40	130
1982	0.063	29	4.28	107
1983	0.045	22	4.09	167
1984	0.024	27	1.85	5
1985	0.012	16	1.40	5
1986	0.014	14	2.10	77

[a] Observed during June census flights that surveyed 1,997 ha.
[b] CV = coefficient of variation.

more pronounced among females than among adult males. Indeed, females in some populations exhibited facultative territoriality in winter and seemed to lay exclusive claim to the highest quality cliff habitats (Hutchins and Geist 1987).

Size of seasonal or year-round home ranges of goats was not calculated during our studies. Radio-instrumented goats in other populations had small annual home ranges of 6–25 km^2 (Rideout 1977; Thompson 1980; Singer and Doherty 1985). Winter home ranges were much reduced—in some instances to 1 km^2 (Smith 1976).

Physiological Ecology

We contrasted live weights of wild and captive-reared mountain goats from KR to determine if weight differences might reflect the extent of resource limitation (Houston et al. 1989). Age-specific body weights of 180 wild goats varied considerably; coefficients of variation ranged from 15 to 22% of the mean body mass for the 1- to 3-year-old males and females (Fig. 31). Goat population size contributed to this variation because mass increased as goat density was reduced (see Chapter 5). Wild females reached maximum body mass at 3 or 4 years; wild males at 5 years. Mass of wild males and females did not differ from kid through 3-year-old classes, but pronounced sexual dimorphism in body mass occurred by age 4. Body mass of wild yearlings, 2-year-olds, and 3-year-olds in July was only 55–68% of that of captive-reared animals of the same age (Houston et al. 1989).

We know little about the seasonal patterns of growth in wild goats. Captive goats, however, gain weight rapidly from May to October, and either remain stable or lose mass from November to April (Houston et al. 1989). Yearling and older males lost weight beginning in late October (about 1 month before rut), and the loss became more pronounced with age. Captive males averaged 75 kg and females averaged 70 kg before breeding at about 1.5 years of age. Captive males reached approximately 65% of their mean adult body mass by their first breeding season; captive females, 80%.

Even when fed high quality food year-round, growth of captive goats varied seasonally (Houston et al. 1989), a pattern common to other ungulates living in the North Temperate Zone (e.g., Wood et al. 1962). Wild goats on KR required considerably longer than did captives to reach the same body mass. Sexual maturity occurred earlier in captive as compared to wild goats.

Little is known about the nutritional physiology of mountain goats. Theory and studies of other species suggest that medium to small ungulates, such as mountain goats, should select high quality foods that are digested rapidly (e.g., Bell 1971; McNaughton and Georgiadis 1986; Baker and Hobbs 1987). Such selection is necessary to maintain the relatively high metabolic rates of

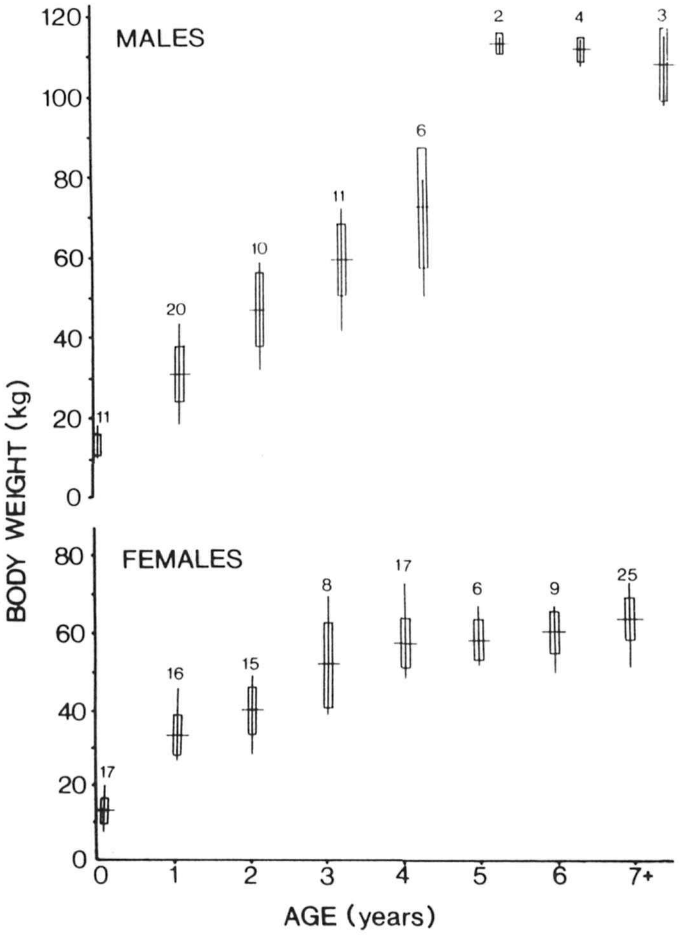

Fig. 31. Body weights of male and female mountain goats in relation to age, Klahhane Ridge. Values represent sample size with mean, range, and 1 SD.

the smaller species. Limited dietary studies suggest that goats might follow this strategy, but no experimental studies of digestive efficiency are available.

Mineral requirements are poorly understood. Mountain goats show much lower dietary selenium requirements than domestic animals, and this has been interpreted as an adaptation to low-selenium environments (Robbins et al. 1985). Sodium may be deficient in soils and vegetation of alpine areas that receive heavy precipitation, and salt craving displayed by goats in the Olympic Mountains in spring and early summer may reflect reduced availability of this element (Robbins 1983).

Interpretation

The remarkably catholic diet and versatile foraging behavior of the mountain goat seem to compensate for their comparatively narrow habitat preference (Geist 1962). The ability of the mountain goat to consume a wide variety of plants has surely contributed to successful colonization of the ecologically diverse Olympic Mountains in less than 60 years. Slower body growth and associated lag in sexual maturity exhibited by wild goats, compared with captive-reared animals, underscores our contention that at least some subpopulations in the Olympics were resource-limited.

Geist (1987) argues persuasively that the duration of the annual productivity pulse of vegetation (i.e., the period of release from shortages in quality and quantity of food resources) has been a powerful force in shaping the ecology and evolution of Pleistocene herbivores. In the mountain goat, life habits, physiology (including seasonality of growth), and behavior seem closely aligned with this seasonal pulse. In the Olympic Mountains, goat migrations to resource-rich—but only seasonally available—summer ranges precede periods of growth, lactation, and fat accumulation. Migrations prolong access to abundant, high quality resources by effectively extending the productivity pulse.

The ability to persist in small groups organized along dominance hierarchies permits mountain goats to successfully exploit isolated, small pockets of resources. Among social animals in general, dominant females often show superior breeding success (Clutton-Brock and Albon 1985). This may be true for mountain goats, but it has not been demonstrated.

Chapter 7. Interspecific Relations

D. B. Houston and E. G. Schreiner

Concern has been expressed about interspecific competition between goats and the native fauna of the Olympic Peninsula (National Park Service 1987) because the distribution of mountain goats and other herbivores overlap seasonally. Data bearing directly on the issue of competitive interactions, however, are scant.

Herbivores

Ungulates

Roosevelt elk (*Cervus elaphus roosevelti*) and black-tailed deer show two life-history patterns in the park: year-round residence at low elevations and seasonal migrations to high elevation summer ranges (Houston et al. 1990). Migratory elk, deer, and goats were broadly associated on subalpine summer ranges; for example, 244 elk, 109 deer, and 396 goats were tallied in counting units during the July 1983 goat census (see Chapter 4). Similar results occurred during the 1990 count; 273 elk and 99 deer occurred in the units with 172 goats. The extensive survey of herbivory on subalpine and alpine summer ranges also showed broad overlap in use of plant communities among goats, elk, deer, and marmots (see Chapter 9). That survey and a radiotelemetry study (Schroer 1987) suggested that elk tended to select highly productive meadows in cirques rather than the sparsely vegetated ridges occupied by goats.

Microhistological examination of fecal pellets showed that elk diets from subalpine summer ranges contained 30 plant taxa; 32 taxa occurred in deer diets. Diets of both cervids were composed mainly of forbs and grasses, but forbs were relatively more important in deer diets (Table 21). Thus, summer diets of elk and deer in subalpine areas were dominated by high quality herbaceous forage. Several plant taxa were common to diets of the three ungulates in these limited samples (*Carex* spp., *Luzula* spp., and *Vaccinium* spp.), and it seems likely that, parkwide, many more taxa would be consumed in common. However, limitations on either the quantity or the quality of food resources for ungulates are least likely during summer in the Olympic Mountains (see Chapter 6). Mere overlap in distribution or diets among species is insufficient to demonstrate interspecific competition.

Observations of elk, deer, and goat distributions during winter, when resources are most likely limited, suggested little overlap between goats and the other ungulates. Elk and deer occupied valley bottoms and slopes below

Table 21. Summary of Roosevelt elk (*Cervus elaphus roosevelti*) and black-tailed deer (*Odocoileus hemionus*) diets from subalpine ranges in Olympic National Park, 1989.[a]

Plant taxa[b]	Percent composition of diets			
	June	July	August	September
	Elk			
Forbs		48	49	53
Lupinus spp.		1	7	8
Potentilla spp.		[c]	6	0
Polygonum spp.		0	3	5
Miscellaneous		13	11	14
Unknown		34	22	26
Grasses and grasslike plants		30	42	32
Carex spp.		7	5	15
Luzula spp.		9	15	5
Miscellaneous		7	11	7
Unknown		7	11	5
Shrubs		17	8	13
Miscellaneous		5	3	5
Unknown		12	5	8
Conifers		5	1	2
Miscellaneous		5	1	2
	Deer			
Forbs	62	64	78	56
Cerastium spp.	5	1	0	0
Fragaria spp.	0	0	8	1
Lathyrus spp.	6	0	0	0
Lupinus spp.	6	2	4	2
Potentilla spp.	0	3	7	0
Miscellaneous	15	24	25	5
Unknown	30	34	34	48
Grasses and grasslike plants	21	23	13	19
Carex spp.	2	6	2	3
Trisetum spp.	5	0	1	0
Miscellaneous	7	11	7	9
Unknown	7	6	3	7
Shrubs	6	9	4	12
Vaccinium spp.	[c]	2	1	5
Miscellaneous	2	3	[c]	0
Unknown	4	4	3	7
~~Miscellaneous~~	~~4~~	~~11~~	~~5~~	
Conifers	11	4	5	13
Abies spp.	7	3	4	8
Miscellaneous	4	1	1	5

[a] Microhistological examinations of samples composited from 10 fecal pellet groups/month, collected at Hurricane Ridge, Deer Park (deer), and Appleton Pass (elk), from 1,500 to 1,700 m elevation. Collections by J. Burger, sample preparation and examination by A. Olson.

[b] Taxa representing ≥5% of at least one monthly sample.

[c] <1%.

about 500 m (Leslie and Starkey 1982; Jenkins and Starkey 1984; Leslie et al. 1984; Houston et al. 1987). Although wintering goats were found both above and below 500 m (see Chapter 6), their affinity for cliffs and rock outcrops suggested a limited potential for interspecific competition, even during winter.

The occurrence and strength of interspecific relations are best demonstrated by experiments where population densities change or are manipulated (Houston 1982; Sinclair and Norton-Griffiths 1982). An average of 15.9 ± 10.50 SD (range = 3–32) deer were tallied during 14 aerial censuses of Klahhane Ridge from 1981 to 1990 as goat density was reduced by more than 98% (see Chapter 4). A regression of deer numbers observed on the estimated goat population showed no significant association ($P > 0.10$, $b = 6.03$, $r^2 = 0.67$), and interspecific competition for resources could not be inferred.

Resource competition between goats and other ungulates has not been demonstrated elsewhere in Washington. However, there is concern that clearcut logging of low-elevation forests has increased elk populations locally and that elk have potential for competing with goats (Johnson 1983).

Small Mammals

The relations between introduced mountain goats and endemic mammals were of interest. The Olympic marmot (*Marmota olympus*) occurs in colonies throughout the subalpine areas of the Olympic Mountains. Marmots hibernate for 7–8 months annually, occupy restricted home ranges while active during summer, and may be food-limited (Barash 1970, 1974; Wood 1973). They forage heavily on forbs and grasses, preferring high-quality new growth of leaves and inflorescences. Plants favored by goats in the Klahhane Ridge area also were utilized by marmots, including *Festuca idahoensis* and *Carex* spp. (Wood 1973). The plot data showed widespread effects on soils from marmot herbivory in subalpine areas and suggested several factors important in den selection (see Chapter 9). Marmot foraging and digging were powerful disturbance forces shaping the vegetation of subalpine meadows (del Moral 1984). Heavy marmot grazing around colonies reduced graminoids and palatable forbs and increased ruderal and unpalatable species (e.g., *Achillea millefolium*), not unlike effects documented for mountain goats (see Chapter 10).

Marmot occupancy of selected colonies has been sampled occasionally over the past 32 years as part of other field studies. Occupancy of 30 colonies was examined in 1989 in relation to mountain goat occurrence by initially considering the Hurricane Ridge and Royal Basin colonies to be in high-density goat range and the Obstruction Point and the Deer Park colonies to be in low-density range (Table 22). Eleven of 15 colonies occupied in either 1957 or 1967–69 on Hurricane Ridge and vicinity were still occupied in 1989 (73%). Nine of these colonies were also known to be occupied in the 1970's. Two colonies in Royal Basin were occupied in 1972 and 1989. For the low-density goat areas, 8 of 12 colonies occupied in either 1957 or 1967–69 were occupied in 1989 (67%), 3

Table 22. Occupancy of 30 marmot (*Marmota olympus*) colonies, Olympic National Park, 1957–1989.[a]

	Years occupied[b]				
Colony site	1957	1967–69	1972	1976	1989
Hurricane Ridge/Hurricane Hill					
Meadow E end parking lot		Y			Y
E basin below Sunrise	Y	Y	Y		Y
N end of Sunrise Basin	Y	Y	Y		Y
Benches N of trails	Y	Y			Y
Basin with Poma lift		Y	Y		Y
Mount Angeles trail		Y			Y
E-facing basin, Mount Angeles trail		Y	Y	Y	Y
Meadow above Wolf Creek	Y	Y	Y		Y
Basin S of Hurricane Hill	Y	Y	Y		Y
SW–facing meadow below trail		Y	Y		Y
S of Hurricane Hill–Elwha trail	Y	Y	Y		Y
N of Hurricane Hill summit		Y			?
E of Hurricane Hill summit	Y				?
Rockpile SE of Hurricane Hill	Y				N
Hurricane Hill–Elwha trail		Y	Y		N
Royal Basin					
E side of Royal Basin			Y		Y
W–SW upper Royal Basin			Y		Y
Obstruction Point/Grand Valley					
Head Badger Valley	Y		Y		Y
Elk Mountain summit			Y		Y
Tarn W of Grand Valley trail	Y				?
Tarn E of Grand Valley trail	Y				N
Meadow below Steeple Rock	Y	Y			Y
Eagle Point	Y	Y	Y		Y
Meadow between switchbacks		Y			Y
Deer Park					
E Blue Mountain summit	Y				Y
Meadow below campground	Y	Y			Y
Ridge S of campground	Y				Y
Slope N of rocky ridge	Y				Y
Slope S of road	Y				N
Roadside above campground	Y				N

[a] 1989 survey and data collation by J. Burger; records from M. Meagher (Olympic National Park, unpublished report, 1957), Barash (1970; personal communication, 1989), Wood (1973; personal communication, 1989), and Watson (1976).

[b] Y = occupied; N = unoccupied; ? = occupancy could not be determined; blank = not checked.

were unoccupied, and occupancy could not be determined for 1. If these colonies were assumed to be representative samples, then the proportion occupied over time did not differ between high and low goat density areas (χ^2 test, $P > 0.10$).

At this broad level of resolution, high densities of goats by the 1970's did not result in competitive exclusion of marmots from the sampled areas. Unfortunately, however, marmot dens surveyed at Hurricane Ridge were virtually all on the periphery of the most intensively used goat areas, so they did not provide a good measure of potential interspecific effects at high goat densities. Although marmots occurred throughout the Hurricane Ridge area and seem to have persisted during the period of high goat density, we cannot discount possible effects on colonies that may have involved reduced densities, reduced recruitment, or elimination.

Distribution of the endemic Olympic pocket gopher (*Thomomys mazama melanops*) seems to have declined from that reported historically (Johnson 1977, and personal communication, 1992). Surveys in 1949, 1951, and 1976 showed that animals were absent from a site at the headwaters of the Soleduck River and at Canyon Creek divide near Bogachiel Peak, areas where they occurred in 1897 and 1931. The decline may have resulted from habitat fragmentation because subalpine meadows have been invaded by forest during the past century. Interspecific competition with goats seems—to us and to M. L. Johnson—unlikely to have been the force driving the decline in gophers.

At least 16 species of insectivores, rodents, and lagomorphs occur in alpine areas of the Olympic Mountains (Johnson and Johnson 1952; Sheehan 1978; Reichel 1984). Dragavon and Weisbrod (1978) conducted a preliminary survey of small mammals on the south slopes of Klahhane Ridge. They trapped one 50- × 50-m grid in each of two plant communities (*Phlox–Festuca* scree slope and *Artemisia–Festuca–Elymus*) during 10–15 September 1978. Fifty-one individuals were trapped, mostly deer mice (*Peromyscus* spp.; 53%), yellow-pine chipmunk (*Tamias amoenus*; 18%), and Oregon voles (*Microtus oregoni*; 14%). Although they speculated that modification of the plant communities (species richness, physiognomy) by mountain goats might affect distribution of certain small mammals, they also recognized the limited nature of the survey, including the likelihood that differences in species trapped between grids reflected only habitat preferences of the small mammals.

The Oregon vole occupies a wide variety of herbaceous communities in the park. Sheehan (1978) studied density, demography, and diet of Oregon voles in three herbaceous plant communities (*Carex spectabilis*, *Valeriana sitchensis*, and *Saussurea americana*) in the northeastern Olympics. Vole densities and recruitment were greatest in the *Carex* community. Twenty-five plant species were identified in vole diets, including several taxa also consumed by mountain goats (e.g., *Luzula* spp. and *Carex* spp.). Goats are known to alter the species composition of at least the *Carex* spp. community, but we do not know how this may affect voles.

On a broader geographic scale, examinations of the population densities, structures, and individual body weights of small mammals suggested that high-elevation areas in the Pacific Northwest generally represented marginal habitats for many species. Sites often functioned as dispersal sinks for populations found at lower elevation sites; that is, populations in alpine or high subalpine areas seemed to be maintained by the influx of individuals from below (Reichel 1984). Effects of goats on small mammals in these apparently marginal habitats—by altering plant cover, morphology, or composition—are unknown.

Carnivores

Predators in Olympic National Park that are known or suspected of taking mountain goats (either from observations in the park or elsewhere) include cougars (*Felis concolor*), bald and golden eagles (*Haliaeetus leucocephalus* and *Aquila chrysaetos*), black bear (*Ursus americanus*), and coyote (Brandborg 1955; Rideout and Hoffman 1975; Johnson 1983). We consider both cougars and black bears to be abundant in the park. For example, the 56 and 26 bears counted incidentally during the July 1983 and 1990 goat censuses represented respective densities of ~0.25 and 0.11 bear/km^2. However, evidence of actual or attempted predation in the park is scarce and consists of cougar tracks at a goat carcass (Stevens 1980), a cougar observed stalking goat kids (D. B. Houston, personal observation), and three attempts by a golden eagle to take a kid (Hutchins 1984). Predation on goats is considered a comparatively minor source of goat deaths in the park. We have more records of deaths by falls than predators. Observations of goats dead from winter mortality, falls, or other causes suggested that carcasses were consumed rapidly by an array of scavengers including ravens (*Corvus corax*), crows (*C. brachyrhynchos*), gray jays (*Perisoreus canadensis*), coyotes, and bears.

Interpretation

Relations between goats and the established native fauna in the Olympic Mountains are obscure. Goats clearly coexist in the nearby Cascade Mountains and elsewhere in western North America with the same species (or near relatives) as those in the Olympics. This suggests that interspecific competition for resources, involving either interference or exploitation as components of the competitive relation (Miller 1967), may be mitigated through resource division.

Still, it seems unlikely to us that herbivores as large as mountain goats could be introduced into the Olympic Mountains, modify the vegetation to the extent documented, reach local densities of 0.08 animal/ha, and not affect the distribution or abundance of the pre-existing fauna. Goats seem most likely to have affected populations of small mammals (and perhaps ground-nesting birds?)

associated with rock outcrops, cliffs, and similar sparsely vegetated sites because of their modification of the vegetation—but even this cannot be demonstrated empirically. In addition, goat deaths have likely increased food supplies for carnivores, particularly at high elevations.

Mountain Goat Herbivory

Chapter 8. A Perspective on Herbivory and the Research Hypotheses

E. G. Schreiner

Plant–herbivore grazing systems have been the subject of increased study during the last 2 decades. Herbivores have been shown to affect numerous attributes of vegetation including plant morphology, species composition, species and plant abundances, net primary productivity, and the genetic makeup of plant populations (e.g., McNaughton 1983; Pastor et al. 1988; Frank and McNaughton 1992). The scale of plant–herbivore interactions ranges from effects on individual plants to ecosystems (Harper 1977; McNaughton 1979, 1983; Crawley 1983). Effects of herbivores have been documented in long-established natural ecosystems (Coppock et al. 1983) and where wild ungulates have been recently introduced (Caughley 1970a; Leader-Williams et al. 1987).

Characteristically, ungulates and vegetation are linked by strong feedback loops between the dynamics of the plants and the dynamics of the animals (Caughley 1970b, 1976b). Ungulate populations may be limited by available food resources; consequently, available per capita resources decrease (i.e., palatable plants) as their populations increase. Natural mortality increases and natality decreases because of insufficient food. The plants feedback to cause a new, lower level of the animal population. Plants and ungulate populations fluctuate with decreasing amplitude over time as dynamic equilibrium is achieved and profound changes usually occur in the vegetation. Caughley (1970a) described this process for another introduced mountain ungulate, the Himalayan thar (*Hemitragus jemlahicus*), in New Zealand.

Mountain goats are generalist herbivores strongly associated with cliffs and rock outcrops (see Chapter 6; Chadwick 1983). Diets seem to be dictated more by the available plant resource than by a preference for any particular species or growth form. Previous studies of the interactions between mountain goats and their summer range in the Olympic Mountains (Table 23) demonstrated that goats changed native ecosystems. Physical site characteristics—such as rock outcrops used for escape terrain and late-melting snow for thermoregulation—were the most important factors in habitat selection by goats; plant community composition was relatively unimportant (Stevens 1979; Pfitsch and Bliss 1985). As a consequence, mountain goats utilized all nine subalpine and alpine plant communities in one study area (Pfitsch and Bliss 1985). Plant community effects included reduced moss and lichen cover, increased soil disturbance and exposure of mineral soil from wallowing and trampling, an increase in ruderal (disturbance-oriented) species (Pfitsch 1981; Pike 1981; Pfitsch et al. 1983; Reid 1983; Pfitsch and Bliss 1985), and a decrease in palatable species. In

Table 23. Studies of the interactions among introduced mountain goats (*Oreamnos americanus*), vegetation, and soils in Olympic National Park, 1976–1986.

Year	Topic	Location	Investigator	Source
1976	Wallow distribution and general impact patterns	Klahhane Ridge	I. Olmsted	Olmsted (1979) Driver et al.[a]
1978–80	Goat effects on two endemic and one regional endemic plant species	Mount Angeles Tyler Peak	D. Pike	Pike (1981)
1979–81	Goat effects on subalpine plant communities	Mount Angeles Tyler Peak Constance Pass	W. Pfitsch	Pfitsch (1981) Pfitsch and Bliss (1985)
1981–82	Wallow size, meadow and wallow erosion	Klahhane Ridge	J. Harter	Pfitsch et al. (1983)
1981–83	Seedling establishment in relation to goats	Klahhane Ridge Hurricane Hill	R. Reid	Reid (1983)
1983–85	Continuation of exclosure studies by Pfitsch (1981)	Mount Angeles	ONP crew	Schreiner (1987)
1984	Continuation of wallow and meadow erosion studies by Pfitsch et al. (1983)	Klahhane Ridge	ONP crew	Houston et al.[b]
1985–86	Endemic milkvetch demography, autecology, and density	Griff Peak to Deer Park	T. Kaye	Kaye (1989)

[a] C. H. Driver, V. Stevens, and D. Pike. Mountain goat population and habitat studies in Olympic National Park, University of Washington, unpublished report, 1978.

[b] D. B. Houston, B. B. Moorhead, E. G. Schreiner, and R. W. Olson. Mountain goat ecology and management investigations, Olympic National Park, unpublished report, 1984.

addition, three Olympic Peninsula and one Olympic Peninsula and Vancouver Island endemic plant taxa were consumed by goats (Pike 1981; Kaye 1989; see Chapters 6 and 12).

Previous studies were conducted primarily on Klahhane Ridge from 1979 to 1982. We began investigations in 1981 to extend understanding of the interactions among mountain goats, vegetation, and soils in time and space. We also examined relations between plant communities and other herbivores on the 43,500 ha of land free of glacial ice above 1,520 m (i.e., goat summer range) and tested two general null hypotheses:

1. Reducing mountain goat densities will not result in changes to the relative abundance of plant species.
2. Mountain goats pose no threat to the long-term persistence of rare plants.

Independent study methods used during the investigations included the following:

1. extensive surveys of vegetation composition and herbivore use in areas of high, medium, and low goat density (see Chapter 9);
2. permanent plots to quantify plant community responses to intentional reductions in goat density (see Chapter 10);
3. a qualitative assessment of changes documented by repeat photographs to examine the effects of climate, human use, natural disturbance, and mountain goats on vegetation and soils over a 70-year period (see Chapter 11); and
4. measures of the general distribution, abundance, and trends in rare plants and a rare endemic (Olympic Mountain milkvetch [*Astragalus australis* var. *olympicus*]) to evaluate effects of mountain goats on the long-term persistence of these taxa (see Chapter 12).

Chapter 9. Interactions Among Herbivores, Plants, and Soils

E. G. Schreiner

Evidence of animal presence was recorded in the sample plots used to classify plant communities in mountain goat summer range (Appendix A1).[12] Scat piles, tracks, wallow or bedding sites, and marmot dens found in each plot were counted. In addition, the number of wallow or bedding sites and marmot dens within 50 m of each plot and the number of trails crossing each plot were tallied. A grazing index for each plant species was obtained by estimating the proportion of plants with evidence of substantial grazing in each plot (Appendix A1). An individual plant was considered to be substantially grazed only if at least 25% of the foliage or stems had been cropped. It was not our intent to estimate the amount of standing crop removed by herbivores. Instead, we sought to create an index of grazing that could be compared among plots, areas, and plant communities.

Herbivore grazing was assessed using several parameters (Appendix A1). Average grazing represented the intensity of grazing on individual plots (grazing index averaged for all species in a plot). Percent of species grazed (PSG) was calculated by comparing the number of species with evidence of substantial grazing to the total number of species in a plot. Values of PSG greater than 50% showed that herbivores grazed a majority of the species present in a plot, and values less than 50% indicated that herbivores were more selective, grazing relatively few of the species present within a plot. A general index of plant species selection by herbivores was calculated by dividing grazing frequency by plant frequency in all plots. This measured how often a species was grazed relative to its availability. Pfitsch and Bliss (1985) described a similar index called species relative grazing frequency (SRGF). They classified species as preferred (SRGF ≥ 50) or avoided (SRGF ≤ 25). However, because they did not consider the overall availability of forage species, their index did not actually provide an estimate of relative preference or avoidance in the conventional sense (Crawley 1983). To allow comparisons with their work (and so we could use their preferred and avoided species in analyses), we used similar criteria but have classified species as selected (SRGF ≥ 50) or nonselected (SRGF ≤ 25) using our plot data.

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[12] The number of plots analyzed here does not always match the number described in Appendixes A1 and A2 (plant community methods and descriptions) because we did not include the few plots with missing herbivory data (e.g., number of wallows). Plots with missing herbivory data still contained valid plant cover data that were used for plant community classification.

An index of the frequency with which each herbivore species used plant communities was created. The three species of ungulates (elk, deer, goats) were considered to have been present in a plot if their pellet groups, tracks, or wallow or bedding sites occurred. Marmots were considered present if a den was located. We also tallied the number of wallow or bedding sites and marmot dens within 50 m of a plot. Tabulations were necessarily biased in favor of ungulates because their sign was most prominent. Marmot activity was underestimated because only dens were used as an indicator of their presence even though tracks and scat piles were noted. Most evidence of mammals smaller than marmots resulted from direct observations, holes, or mounds of scat from winter activity. Twenty-two areas were classified into three categories of estimated goat density (Fig. 32): high (>3 goats/km^2), medium (1–3 goats/km^2), and low (<1 goat/km^2).

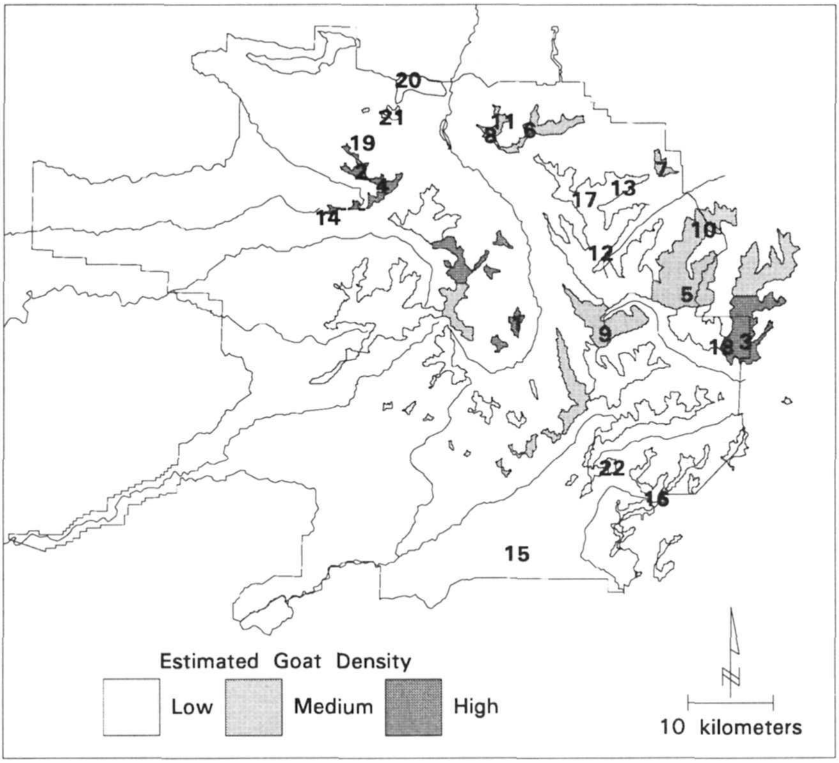
Patterns of Herbivore Sign

Considerable evidence of animal activity was observed. Herbivores included elk, mountain goats, deer, marmots, chipmunks (*Tamias* spp.), pocket gophers, voles (*Microtus* spp.), mountain beaver (*Aplodontia rufa*), and snowshoe hare (*Lepus americanus*). In addition, weasels (*Mustela* spp.), black bear, and coyotes or their sign were observed in five plots. Insect herbivory was noted everywhere but did not seem to account for the removal of large quantities of plant biomass.

Evidence of mountain goats was found in every sample area (Table 24). Goat pellet groups, tracks, or wallows occurred in 229 (33%) plots and within 50 m of 310 (44%). The proportion of plots with goat sign was 38% in high, 51% in medium, and 8% in low goat density areas. Marmot dens were found inside 33 (5%) and outside (within 50 m) of 170 (24%) plots in 16 of the 22 study areas. There was no obvious relation between goat density and the number of plots with marmot dens.

Sign of elk and deer occurred regularly in and around plots (Table 24). Deer and unidentified ungulate sign was observed with the highest frequency, occurring in 82 (12%) of the plots. Elk sign was encountered in only four sample areas but was locally abundant. At Hoh Lake, for example, 39% of the plots contained elk sign. Similarly, 57% of the plots at Schoeffel Creek had elk sign. Sign of other species including bear, mountain beaver, voles, chipmunks, and snowshoe hare was encountered infrequently compared with that of ungulates.

The larger sample size afforded by counting wallows and marmot dens within 50 m of plots increased the proportion of plots with evidence of the four herbivores. Marmot dens were observed near 27% of high, 17% of medium, and 27% of low goat density plots; goat wallows or beds were found near 68% of high, 49% of medium, and 4% of low-density plots. The percentage of plots with elk, deer, and unidentified ungulate wallows or beds within 50 m of plots was generally low except at Hoh Lake. Eleven wallows outside of plots at Hoh Lake were identified as deer and unidentified ungulate—we assume elk were responsible.



KEY TO LOCATION NUMBERS

Code	Area Name	Code	Area Name
1	Mount Dana	12	Grand Valley
2	Mount Appleton	13	Maiden Peak
3	Mount Constance	14	Hoh Lake Cirque
4	Schoeffel Creek	15	Six Ridge
5	Royal Basin	16	Mount Stone
6	Mount Angeles	17	Obstruction Peak
7	Deer Park	18	Constance Pass
8	Hurricane Hill	19	Crystal Ridge
9	Sentinal Peak	20	Baldy Ridge
10	Greywolf Ridge	21	Happy Lake Ridge
11	Griff	22	Mount Steel

Fig. 32. Location of study areas in relation to estimated mountain goat density; from National Park Service (1987).

Table 24. Number of plots (%), by species, with an herbivore index (HI) greater than zero. Mountain goat (*Oreamnos americanus*) density estimates, except for Mount Angeles 1982 and Deer Park 1988, are from National Park Service (1987).

Area	*n*	Goats	Marmots	Elk	Deer[a]
High goat density (>3 goats/km^2)					
Mount Dana	189	85 (45)	3 (2)	0 (0)	24 (13)
Mount Appleton	86	26 (30)	9 (10)	3 (3)	2 (2)
Mount Constance	16	5 (31)	0 (0)	0 (0)	0 (0)
Schoeffel Creek	14	1 (7)	3 (21)	8 (57)	1 (7)
Mount Angeles (1982)[b]	7	2 (29)			
Total	312	119 (38)	15 (5)	11 (4)	27 (9)
Medium goat density (1–3 goats/km^2)					
Royal Basin (1981)	53	12 (23)			
Mount Angeles (1985–86)[c]	44	26 (59)	0 (0)	0 (0)	5 (11)
Deer Park (1985–86)[c]	25	12 (48)	0 (0)	0 (0)	4 (16)
Royal Basin (1983)	29	26 (90)	3 (10)	0 (0)	1 (3)
Hurricane Hill (1985–86)[c]	6	2 (33)	0 (0)	0 (0)	0 (0)
Mount Angeles (1985)	7	7 (100)	0 (0)	0 (0)	0 (0)
Sentinel Peak	5	4 (80)	1 (20)	0 (0)	0 (0)
Greywolf Ridge	4	1 (25)	0 (0)	0 (0)	0 (0)
Deer Park (1984)	3	0 (0)	0 (0)	0 (0)	1 (33)
Griff Peak (1985–86)[c]	3	2 (67)	0 (0)	0 (0)	1 (33)
Hurricane Hill	2	1 (50)	0 (0)	0 (0)	0 (0)
Total	181	93 (51)	4 (2)	0 (0)	12 (7)
Low goat density (<1 goat/km^2)					
Grand Valley	97	2 (2)	9 (9)	0 (0)	17 (18)
Maiden Peak	23	1 (4)	3 (13)	0 (0)	9 (39)
Hoh Lake Cirque	23	0 (0)	2 (9)	9 (39)	9 (39)
Six Ridge	11	0 (0)	0 (0)	3 (27)	2 (18)
Constance Pass	12	3 (25)	0 (0)	0 (0)	0 (0)
Mount Stone	9	0 (0)	0 (0)	0 (0)	0 (0)
Deer Park (1988)	8	1 (13)	0 (0)	0 (0)	5 (63)
Obstruction Peak	8	1 (13)	0 (0)	0 (0)	0 (0)
Crystal Ridge	7	7 (100)	0 (0)	0 (0)	0 (0)
Baldy Ridge	4	1 (25)	1 (25)	0 (0)	0 (0)
Mount Steel	2	0 (0)	1 (50)	0 (0)	1 (50)
Happy Lake Ridge	2	1 (50)	0 (0)	0 (0)	0 (0)
Total	206	17 (8)	16 (8)	12 (6)	43 (21)
Grand total	699	229 (33)	35 (5)	23 (3)	82 (12)

[a] Includes unidentified ungulates.

[b] Place names that appear more than once reflect goat density at the time of sampling (i.e., goat density changed between sample years).

[c] *Astragalus australis* var. *olympicus* plots.

Herbivores and Soil Disturbance

The most conspicuous soil disturbances encountered were produced by wallowing and bedding—mostly by goats. Goat wallow or bed sites occurred high on slopes and had expansive views, presumably so that predators had little opportunity to surprise wallowing or resting animals. The typical wallow was a flat spot of exposed mineral soil where surface rocks had been removed and any vegetation present had been eliminated. Most wallows were 1–3 m^2 with the disturbed area extending an additional 1–2 m downslope. Wallows up to 20 m^2 also were encountered. More than 700 wallows were counted—most were in high and medium goat density areas (Table 25). Soil disturbances accompanied by elk, deer, and unidentified ungulate sign occurred mostly in low goat density areas. More than 100 elk, deer, and unidentified ungulate wallows were counted—76 were at Hoh Lake (low goat density) where elk use prevailed.

The number and frequency of tracks, trails, and pellet groups in each area were a rough measure of trampling disturbance. We could not determine which large herbivore created trails, but patterns suggested that goats were often responsible. We counted 139 trails crossing 312 plots in high goat density areas and 59 crossing 206 plots in low density areas. Similarly, 149 goat pellet groups were tallied in high density plots compared to only 4 in low density plots. Deer and unidentified ungulate tracks exhibited no pattern with goat density; 82 sets of tracks were tallied in high, 58 in medium, and 87 in low goat density plots.

Herbivore–Plant Community Relations

All 16 plant communities were used by herbivores (Table 26). Mountain goat sign was present with the highest frequency followed by deer and unidentified ungulate, marmots, elk, and small mammals. Deer and unidentified ungulate sign was encountered in all community types, and mountain goat sign was found in all but one community type. Mountain goat sign was encountered twice as often as that of any other herbivore in 12 of the 16 community types.

We found no strong pattern between the occurrence of goat or deer and unidentified ungulate sign and plant community type in goat summer range (Fig. 33). Evidence of mountain goats was observed in more than 40% of the plots in some communities and very little or not at all in others. Elk sign was less widely distributed among community types and was most often encountered in three of the *Carex spectabilis* communities and the *Phacelia* scree community type.

The distribution of ungulate pellet groups and marmot dens among community types (Fig. 34) suggests that herbivores used *Carex spectabilis* communities most frequently. Other communities with moderate to high use included the *Phlox–Fes-*

Table 25. Animal sign found inside or within 50 m of plots in mountain goat (*Oreamnos americanus*) summer range of Olympic National Park.[a]

		Goat sign				Elk sign						Deer[b]				
		In			Out	In			Out	Marmot dens		In			Out	Trails inside
Goat density	*n*	T	P	W	W	T	P	W	W	In	Out	T	P	W	W	
High (>3 goats/km^2)	312	107	149	61	394	18	30	70	0	18	159	82	13	0	14	139
Medium (1–3 goats/km^2)	181	189	76	45	190	0	0	0	0	4	61	58	12	1	0	81
Low (<1 goat/km^2)	206	26	4	3	18	5	18	2	0	34	149	87	44	8	69	59
Total	699	322	229	109	602	23	48	9	0	56	369	227	69	9	83	279

[a] Totals are listed: T = sets of tracks; P = pellet groups; W = wallow or bedding sites; In = inside plots; Out = within 50 m of plots.

[b] Includes unidentified ungulates.

Table 26. Number of plots (%), by plant community type, with an herbivore index greater than zero in mountain goat (*Oreamnos americanus*) summer range in Olympic National Park.

Community type	*n*	Goats	Marmots	Elk	Deer[a]
Scree					
Astragalus	50	28 (56)	0 (0)	0 (0)	4 (8)
Phacelia	41	17 (41)	5 (12)	3 (7)	7 (17)
Delphinium	13	6 (46)	0 (0)	0 (0)	1 (8)
Senecio	14	1 (7)	0 (0)	0 (0)	2 (14)
Phlox diffusa					
Potentilla	45	12 (27)	0 (0)	0 (0)	6 (13)
Festuca	44	9 (20)	2 (5)	4 (9)	11 (25)
Carex phaeocephala	42	11 (26)	1 (2)	1 (2)	2 (5)
Juniperus	42	14 (33)	0 (0)	2 (5)	3 (7)
Pachistima–Sedum	76	24 (32)	0 (0)	0 (0)	2 (3)
Pachistima–Phacelia	15	7 (47)	1 (7)	0 (0)	2 (13)
Carex spectabilis					
Valeriana	39	8 (21)	6 (15)	6 (15)	4 (10)
Vaccinium	30	9 (30)	4 (13)	3 (10)	4 (13)
Lupinus	94	31 (33)	12 (13)	0 (0)	23 (24)
Phyllodoce	56	23 (41)	3 (5)	3 (5)	7 (13)
Cassiope	34	17 (50)	1 (3)	0 (0)	3 (9)
Late snowmelt					
Luetkea–Saxifraga	5	0 (0)	0 (0)	0 (0)	1 (20)
Total	640	217 (34)	35 (5)	22 (3)	82 (13)

[a] Includes unidentified ungulates.

tuca, *Phacelia* scree, *Phyllodoce*, and *Cassiope* communities. Goat pellet groups were more abundant in areas with high or medium goat density than those with low goat density. Marmot dens occurred most frequently in the *Phacelia* scree, *Phlox–Festuca* and the three *Carex spectabilis* communities (*Valeriana*, *Vaccinium*, *Lupinus*). These five communities have relatively little bedrock at the soil surface.

Grazing Patterns

Determining which herbivore species was responsible for consuming plants was difficult in the absence of direct observations. Evidence of herbivores (i.e., sign) within or in the vicinity of plots where grazing occurred was used to infer the species likely responsible for the grazing, but accuracy was not assured. Hence, results were interpreted conservatively.

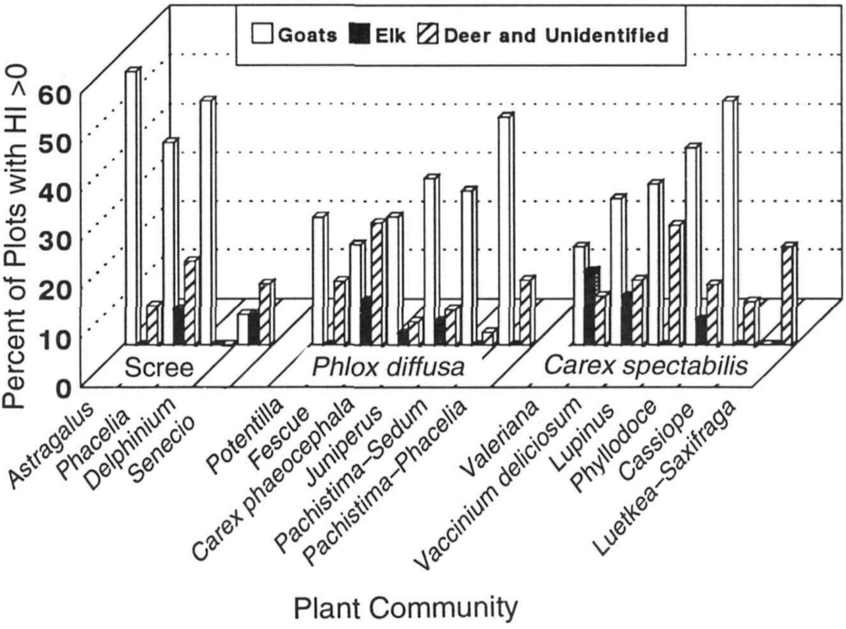


Fig. 33. Percentage of plots with an herbivore index (HI) >0 for three species of ungulates by community type.

Two measures—percentage of species grazed and average grazing—provided a crude measurement of herbivory by community type and estimated goat density (Fig. 35). The percentage of species grazed was largest in high or medium goat density areas across all 16 community types. This indicated that, for a particular community type, herbivores were less selective when grazing in high or medium density areas compared to low goat density areas. Average grazing generally followed the same pattern except that, in low goat density areas, it was highest in the *Senecio* and *Carex–Valeriana* community types.

A rough idea of plant species selected by mountain goats on a parkwide basis was obtained by comparing species relative grazing frequency and average grazing of species that occurred in high, medium, and low goat density areas (Table 27). *Carex spectabilis*, *Poa secunda*, *Agoseris* spp., *Festuca idahoensis*, *Hedysarum occidentale*, *Valeriana sitchensis*, and the endemic *Aster paucicapitatus* had relatively high average grazing in areas with high goat density compared with medium or low goat density areas. Additionally, relative grazing frequency for each of these species in high density areas was at least 2.6 times greater than in low density areas. These same species (except *Valeriana sitchensis*) were identi-

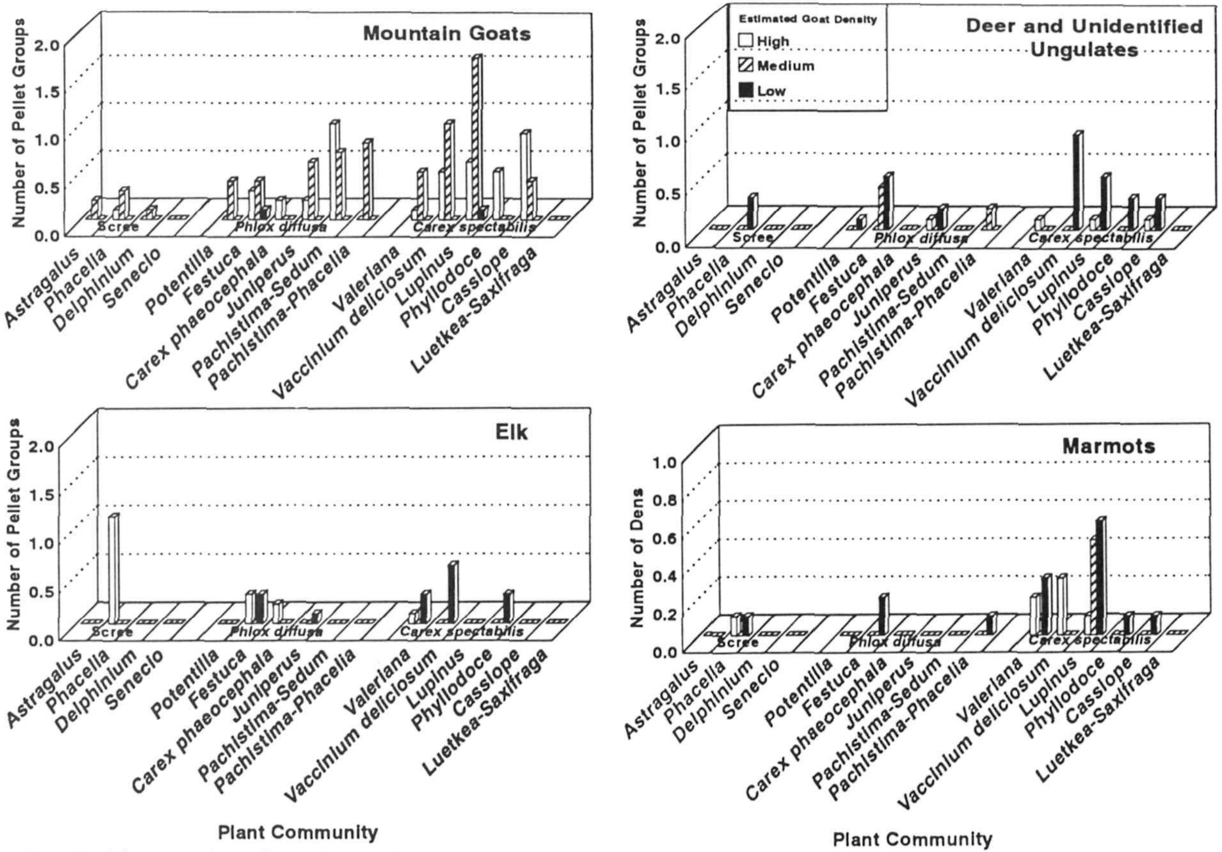
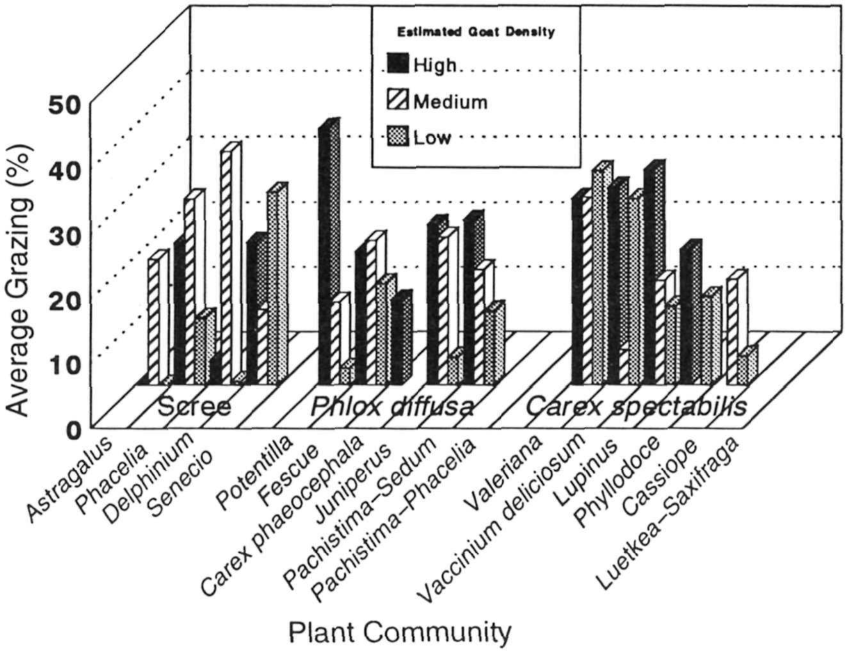


Fig. 34. Mean number of ungulate pellet groups and marmot dens in plots by community type.



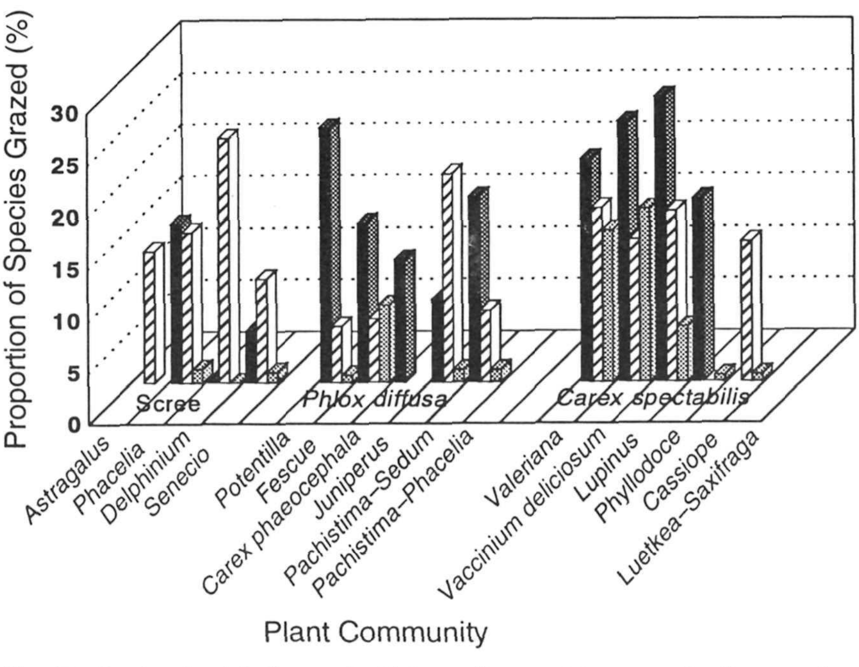


Fig. 35. Grazing level indicators in high, medium, and low goat density areas by community type; average grazing (*top*) and proportion of species grazed (*bottom*).

Table 27. Average grazing, plant frequency, grazing frequency, and species relative grazing frequency (SRGF) for plant species in mountain goat (*Oreamnos americanus*) summer range of Olympic National Park.[a]

	Average grazing (%)			Frequency (*n*)						SRGF			SRGF ratios	
				Plant			Grazing							
Species	H	M	L	H	M	L	H	M	L	H	M	L	H/L	M/L
						Selected species[b]								
Carex spectabilis[c]	12.7	2.3	6.6	158	30	75	126	20	21	80	67	28	2.8	2.4
Poa secunda[c]	7.6	1.3	0.7	103	58	37	52	16	4	50	28	11	4.7	2.6
Agoseris spp.[c]	7.6	3.2	1.0	114	54	56	63	16	12	55	30	21	2.6	1.4
Festuca idahoensis[c]	6.8	2.8	3.8	15	52	35	13	17	10	87	33	29	3.0	1.1
Hedysarum occidentale[c]	6.1	2.8	0.1	47	18	13	19	5	1	40	28	8	5.3	3.6
Valeriana sitchensis	5.0	0.2	1.1	63	14	21	29	3	3	46	21	14	3.2	1.5
Aster paucicapitatus[c]	4.7	1.6	0.1	77	25	25	33	14	1	43	56	4	10.7	14.0
Erigeron peregrinus[c]	3.4	0.4	1.4	97	19	28	44	7	6	45	37	21	2.1	1.7
Sitanion hystrix	3.2	1.0		32	65	42	12	10		38	15			
Luzula parviflora	3.1	1.3	T	50	11	25	18	4	3	36	36	12	3.0	3.0
Carex phaeocephala	2.8	0.6	T	74	22	30	27	12	1	36	55	3	10.9	16.4
Phacelia hastata	2.3	1.5	0.9	73	66	29	30	15	4	41	23	14	3.0	1.6
Carex rossii	2.2	1.3	2.8	41	23	11	24	5	3	59	22	27	2.1	0.8
Trisetum spicatum	2.2	1.6		116	47	38	50	14		43	30			
Luzula campestris	2.1	0.1	1.2	104	26	43	39	7	4	38	27	9	4.0	2.9
Erysimum arenicola[d]	2.0	0.7		95	67	46	27	9		28	13			
Hieracium albiflorum	1.8	0.4	0.7	34	23	11	18	3	2	53	13	18	2.9	0.7
Hieracium gracile[d]	1.8	0.2		141	31	38	49	8		35	26			
Phleum alpinum	1.8	0.6	0.2	31	10	18	13	4	2	42	40	11	3.8	3.6
Juncus parryi	1.6	0.4	T	86	34	16	44	9	1	51	26	6	8.2	4.2
Epilobium alpinum	1.6	0.5	0.1	102	51	64	22	8	6	22	16	9	2.3	1.7
Achillea millefolium	1.3	0.6	T	56	108	74	19	16	1	34	15	1	25.1	11.0
Phlox diffusa[d]	1.2	2.2	T	201	135	88	44	21	2	22	16	2	9.6	6.8
Deschampsia atropurpurea[d]	0.9	T	0.9	37	14	23	15	1	3	41	7	13	3.1	0.5

Table 27. *Continued.*

	Average grazing (%)			Frequency (n)						SRGF			SRGF ratios	
				Plant			Grazing							
Species	H	M	L	H	M	L	H	M	L	H	M	L	H/L	M/L
Campanula rotundifolia[c]	0.9	T	0.1	13	14	20	5	2	2	38	14	10	3.8	1.4
Epilobium angustifolium	0.8	0.4		28	24	22		10	5		36	21		
Artemisia ludoviciana	0.7	0.1		11	51	14		4	6		36	12		
Viola adunca	0.7	T	T	44	49	32	10	3	1	23	6	3	7.3	2.0
Cirsium edule[d]	0.7	0.3	T	35	29	13	10	3	1	29	10	8	3.7	1.3
Penstemon davidsonii	0.5	1.5	T	59	39	21	14	9	1	24	23	5	5.0	4.8
Douglasia laevigata	0.3		0.2	105	29	43	13		2	12		5	2.7	
Luetkea pectinata[d]	0.2	0.5	T	139	27	38	25	8	1	18	30	3	6.8	11.3
Veronica cusickii	0.2	0.2	0.2	51	21	40	12	4	1	24	19	3	9.4	7.6
Antennaria lanata[d]	0.7	0.2		25	20	24	5	7		20	35			
Arenaria capillaris	0.4	0.1		66	25	24	10	1		15	4			
Juniperus communis[d]	0.1	0.3		55	31	31	8	4		15	13			
Antennaria microphylla[d]	T	T		74	25	37	9	3		12	12			
Phacelia sericea	0.2	2.2		19	59	26	2	15		11	25			
Penstemon procerus	0.2	0.7		21	30	13	2	7		10	23			
Festuca ovina	0.2	0.7		39	18	20	3	7		8	39			
Sedum divergens	0.2	0.2		110	42	28	8	3		7	7			
Cryptogamma crispa	0.2	0.2		60	21	11	3	2		5	10			
Cassiope mertensiana	T	T		27	15	11	1	3		4	20			
Possibly selected species[e]														
Silene parryi[c]	7.1	5.1	2.9	98	57	36	64	26	13	65	46	36	1.8	1.3
Poa cusickii	3.7	1.5	0.9	107	38	42	46	17	10	43	45	24	1.8	1.9
Pachistima myrsinites	2.7	4.3	0.1	42	45	15	23	14	5	55	31	33	1.6	0.9
Bromus sitchensis[c]	4.0	2.1	1.1	35	34	18	22	12	7	63	35	39	1.6	0.9
Polygonum bistortoides[c]	13.9	1.3	10.7	161	22	64	118	9	31	73	41	48	1.5	0.8
Lupinus latifolius	4.3	1.6	1.3	172	20	42	43	6	7	25	30	17	1.5	1.8
Anemone occidentalis	0.3	1.6	1.7	22	13	14	4	3	2	18	23	14	1.3	1.6
Lomatium martindalei	1.7	1.5	0.3	152	92	57	40	30	12	26	33	21	1.3	1.5

Table 27. *Continued.*

	Average grazing (%)			Frequency (*n*)										
				Plant			Grazing			SRGF			SRGF ratios	
Species	H	M	L	H	M	L	H	M	L	H	M	L	H/L	M/L
	Species with a relatively high value of SRGF in low goat density areas													
Vaccinium membranaceum	12.0	5.0	7.9	76	15	10	50	13	7	66	87	70	0.9	1.2
Artemisia norvegica	0.7	0.9	1.6	22	10	17	4	1	4	18	10	24	0.8	0.4
Castilleja miniata	0.4	2.3	2.3	41	32	27	5	15	10	12	47	37	0.3	1.3
Ranunculus eschscholtzii	1.9		0.4	23	7	14	6		4	26		29	0.9	
Potentilla fruticosa		0.6	T	1	35	26		5	4		14	15	0.9	
Gentiana calycosa	4.3		4.2	65	1	10	23		4	35		40	0.9	

[a] H = high goat density areas (>3 goats/km^2); M = medium goat density areas (1–3 goats/km^2); L = low goat density areas (<1 goat/km^2). The following avoided species listed by Pfitsch and Bliss (1985) did not occur in enough plots to be rated here: *Lathyrus nevadensis*, *Orthocarpus imbricatus*, *Hydrophyllum fendleri*, *Polygonum douglasii*, *Vicia americana*, *Delphinium glareosum*, *Arabis* spp., *Cassiope mertensiana*, *Arenaria rubella.*

[b] Species with 10 or more occurrences in high, medium, and low goat density areas and a species relative grazing frequency at least ×2 higher in high- or medium- compared to low-density areas. These species were categorized as selected by goats on a parkwide basis.

[c] Species listed as preferred by goats on Klahhane Ridge by Pfitsch and Bliss (1985).

[d] Species listed as avoided by goats on Klahhane Ridge by Pfitsch and Bliss (1985).

[e] Species with an SRGF ratio 1:1.9—these species *may* be selected by goats but are also grazed by other herbivores.

fied as preferred mountain goat forage by Pfitsch and Bliss (1985). Thirty-three species, including rushes, forbs, grasses, sedges, ferns, and one shrub, were grazed more frequently in high density areas compared with low goat density areas.

An examination of grazing on individual plant species by area (Table 28) revealed that a species considered selected by goats in one area might be nonselected in another.[13] For example, *Deschampsia atropurpurea* was considered selected forage at Mount Dana and nonselected at Mount Appleton—both areas of high goat density. Additionally, three species (*Carex spectabilis*, *Polygonum bistortoides*, and *Silene parryi*) were selected in one high as well as one low goat density area. We assume these three species were selected also by herbivores other than goats.

Interpretation

Several indicators, including pellet groups, tracks, wallow or bedding sites, grazing, and trails, showed that herbivores interacted extensively with vegetation and soil in mountain goat summer range. Mountain goat sign was most prevalent, followed by marmots, deer and unidentified ungulate, and elk. Mountain goats evidently used or at least traveled through every sample area, even those with low goat density. Marmot sign and deer and unidentified ungulate sign occurred in more than half the sample areas—elk sign was encountered infrequently.

The frequency of herbivore sign in the different areas suggested that there was broad overlap among goats, deer, and marmots in goat summer range and that elk utilized somewhat different areas. Field observations indicated that preferred summer range of migratory elk differed from that of goats—elk used meadows and forests associated with subalpine and upper montane cirques rather than the ridge tops and rocky outcrops occupied by mountain goats. Studies of radio-instrumented elk by Schroer (1987) supported this interpretation of their summer distribution.

Substantial soil disturbance by herbivores was documented. Disturbances in low goat density areas were attributed mainly to elk, deer, and marmots. Mountain goat wallow or bed sites occurred mainly in high and medium goat density areas. Even though the precise effects of trampling and wallowing by mountain goats were not quantified, goat activities have undoubtedly increased disturbance levels. Evidence of disturbance by other herbivores was present but inconsequential compared with goat disturbance in most areas where estimated

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[13] The method used to classify species as selected or nonselected parkwide was based on the relative difference in the value of SRGF in high, medium, and low goat density areas. This criterion (i.e., SRGF in high, medium, and low goat density areas) could not be applied to individual areas because there were no goat density estimates for individual plots. Hence we used the criteria described in Appendix A1 to determine selected and nonselected species (SRGF ≥50, SRGF ≤25) for individual areas (e.g., Mount Dana).

Table 28. Selected (S) and nonselected (N) plant species in high, medium, and low mountain goat (*Oreamnos americanus*) density areas of Olympic National Park.

	Area[a] and estimated goat density												
	High					Medium			Low				
Species	MD	AP	KR[b]	MC	SC	RB	MA	DP	GL	MP	SR	CP	HL
Abies lasicocarpa	N	N				N							
Achillea millefolium			S			N		N	N				
Agoseris spp.	S		S		S		S			N			
Allium cernuum								N					
Allium crenulatum							N	N					
Antennaria lanata	N								N				
Antennaria microphylla	N	N				N			N				
Antennaria racemosa						S							
Arabis spp.							S						
Arenaria capillaris	N								N				
Arenaria macrophylla		N				N							
Arnica latifolia		N				S							
Artemisia ludoviciana						N	N	N	N				
Artemisia norvegica		N								N			
Astralalus australis var. *olympicus*								N					
Aster foliaceus		N											
Aster paucicapitatus						S			N				
Bromus sitchensis							S	N					
Campanula piperi							N	N					
Campanula rotundifolia								N		N			
Carex hoodii						S							
Carex phaeocephala						S			N				
Carex rossii	S	S											

Table 28. *Continued.*

	Area[a] and estimated goat density												
	High					Medium			Low				
Species	MD	AP	KR[b]	MC	SC	RB	MA	DP	GL	MP	SR	CP	HL
Carex spectabilis	S	S				S			N	N			S
Cassiope mertensiana						N							
Castilleja hispida		N											
Castilleja miniata		N											
Castilleja parviflora var. *olympica*	N							N					
Cheilanthes gracillima	N												
Cirsium edule		N				N							
Claytonia lanceolata	N												
Crepis nana							N						
Cryptogamma crispa	N	N				N							
Delphinium glareosum									N				
Deschampsia atropurpurea	S	N				N							
Deschampsia caespitosa							N						
Douglasia laevigata	N	N							N				
Elymus glaucus							N						
Epilobium alpinum	N	N		N	N	N	N		N				
Epilobium glaberrimum						N			N				
Erigeron compositus							N	N	N				
Eriophyllum lanatum							N	N					
Erysimum arenicola						N	N		N				
Festuca idahoensis			S				S	N		N			
Festuca ovina	N	N				S			N				
Fragaria vesca		N											
Hedysarum occidentale							N						

Table 28. *Continued.*

	Area[a] and estimated goat density												
	High					Medium			Low				
Species	MD	AP	KR[b]	MC	SC	RB	MA	DP	GL	MP	SR	CP	HL
Hieracium albiflorum	S					N	N						
Hieracium gracile		N							N				N
Hydrophyllum fendleri						N							
Juniperus communis	N	N				N			N				
Juncus parryi	S								N				
Lomatium martindalei		N		N				N	N				
Luetkea pectinata	N	N							N	N			
Luina hypoleuca		N				N							
Lupinus latifolius	N								N				
Luzula campestris		N							N				
Luzula parviflora										N			
Mertensia paniculata		N											
Osmorhiza spp.		N											
Pachistima myrsinites	S												
Penstemon davidsonii		N					N		N				
Phacelia hastata			S			N			N				
Phacelia sericea							N	N					
Phleum alpinum										N			
Phlox diffusa	N	N	S			N	N	N	N	N			
Pinus monticola						N							
Poa cusickii										N			
Poa secunda									N				
Polygonum bistortoides	S	S	S		S					S			S
Polystichum lonchitis						N							

Table 28. *Continued.*

	Area[a] and estimated goat density												
	High					Medium			Low				
Species	MD	AP	KR[b]	MC	SC	RB	MA	DP	GL	MP	SR	CP	HL
Potentilla fruticosa								N	N				
Saxifraga bronchialis		N				N							
Saxifraga caespitosa		N											
Sedum divergens	N	N				N	N		N				
Sedum lanceolatum									N				
Senecio flettii						N							
Senecio triangularis		N											
Silene parryi	S	S	S			S			N	S			
Sitanion hystrix							N	N	N				
Smelowskia calycina									N				
Solidago multiradiata						N			N				
Thlaspi fendleri		N											
Trisetum spicatum									N				
Vaccinium membranaceum		S				S							
Valeriana sitchensis						N							
Veronica cusickii		N				N		N	N	N			N
Viola adunca		N	S			N	N		N				
Viola glabella		N											

[a] MD = Mount Dana; AP = Mount Appleton; KR = Klahhane Ridge; MC = Mount Constance; SC = Schoeffel Creek; RB = Royal Basin; MA = Mount Angeles; DP = Deer Park; GL = Grand Lake; MP = Maiden Peak; SR = Six Ridge; CP = Constance Pass; and HL = Hoh Lake.

[b] Preferred (S) and avoided (N) species listed by Pfitsch and Bliss (1985).

goat density was high or medium. Few studies have been conducted on herbivore use of subalpine and alpine vegetation within the summer range of mountain goats in Olympic National Park. Kuramoto and Bliss (1970) reported that the Olympic marmot made extensive use of mesic grassy communities (*Phlox–Festuca*); that deer grazed mainly in the mesic grassy, *Saussurea* forb, and tall sedge (*Carex–Lupinus*) communities; and that elk were most often observed using the *Valeriana* forb (*Carex–Valeriana*) and tall sedge communities. Wood (1973) found that marmot colonies were most often in the *Carex spectabilis* (*Carex–Lupinus*), *Phlox–Festuca* and *Carex–Valeriana* communities and less often located in sites dominated by *Saussurea americana*, *Carex nigricans*, or *Phyllodoce empetriformis*. Voles (*Microtus oregonii*) were trapped most frequently in *Carex spectabilis* meadows and less in *Carex–Valeriana* and *Saussurea* forb meadows (Sheehan 1978).

Deer and unidentified ungulate sign occurred most often in the *Carex spectabilis* (tall sedge, *Valeriana* forb) communities and in the *Phlox–Festuca* (mesic grassy) communities. However, the relatively small amount of elk sign encountered above 1,520 m suggests that, at higher elevations at least, elk may use the *Phacelia* scree, and *Phyllodoce* (heath shrub) communities in addition to the tall sedge and mesic grassy communities. Our study supports observations by Kuramoto and Bliss (1970) with respect to plant community use by deer and elk.

Marmot dens in mountain goat summer range occurred in relatively few plant community types. Three factors may be important selection criteria for marmots: snow depth, the amount of bedrock, and, tentatively, some minimum level of standing crop in the community. The first factor is proposed because most marmot dens occurred in plant communities containing *Carex spectabilis*, all of which occurred at the wet, delayed snowmelt end of the community gradient. These observations are similar to those of Wood (1973) and may relate to the observation that marmots perished in their dens overwinter unless there was sufficient snow to provide insulation (Barash 1973). The second factor is proposed because marmot dens were also observed in the relatively early snowmelt *Phacelia* scree and *Phlox–Festuca* communities. In both instances, there is little exposed bedrock; den construction would obviously be difficult in sites with abundant bedrock. The possibility that low-standing crop plays a role in marmot selection of den sites is suggested because communities such as the *Senecio* scree have delayed snowmelt and little bedrock but have low plant cover (i.e., low standing crop). In all likelihood, a combination of these factors influences site selection by marmots.

Mountain goat use of the plant communities seemed to reflect selection for rock outcrops and cliffs rather than for plant species composition. The 16 of 17 plant communities utilized by goats ranged from 7 to 105% plant cover and contained hundreds of plant species, many of which were not shared among community types.

Mountain goats may select certain plant species locally, but there was little consistency among areas; plants selected in one region were not selected in others. This reinforces the interpretation that summer range selection by mountain goats is based more on habitat requirements than on plant communities. Our results were consistent with studies of mountain goats throughout their native range (Casebeer et al. 1950; Brandborg 1955; Adams and Bailey 1983; Campbell and Johnson 1983; Fox et al. 1989) and in the Olympic Mountains (Stevens 1979; Pfitsch and Bliss 1985).

Chapter 10. Responses of Vegetation to Reductions in Goat Density

E. G. Schreiner and A. Woodward

We established permanent plots in three areas of mountain goat summer range to evaluate plant responses to different levels of goat herbivory[14] (Table 29). Each study area had relatively high initial goat density but differed in annual precipitation and the composition of plant communities. The three areas also differed physiographically: Klahhane Ridge extends east–west with mainly north and south exposures, Mount Dana is an isolated peak with all exposures, and Avalanche Canyon is a north–south valley with east- and west-facing exposures. We reduced each goat subpopulation and simultaneously measured vegetation to test the null hypothesis that reducing mountain goat density would not affect the relative abundance of plant species.

Plots were placed in homogeneous vegetation where goat herbivory was initially high, and control plots were placed where herbivory was initially low. Plant cover and grazing levels were estimated on randomly located 1- × 1-m quadrats ($n = 6$–12) in each plot (Appendix A1). We sampled three times per year at Klahhane Ridge, two per year at Avalanche Canyon, and once per year at Mount Dana. More than one measurement per year was taken at Klahhane Ridge and Avalanche Canyon to ensure that we estimated plant cover at the seasonal maximum. Access to Mount Dana was too time-consuming to allow more than one sample per year.

We tested the null hypothesis by comparing total plant cover and cover of selected and nonselected plant species over time in plots with high and low initial levels of goat herbivory (declining herbivory versus stable or increasing herbivory at Avalanche Canyon; see below). We used regressions of plant cover on time and correlation coefficients (r) of cover with weather variables and goat density as descriptive statistics summarizing the association among the variables for each plot. Significant differences in these statistics among treatments were determined using a nonparametric permutation test (Mehta et al. 1988).

Despite the large number of quadrats sampled ($n = 172$), the data set is still composed of small numbers of plots per treatment at any one site because we used

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[14] Exclosures were not used because microenvironmental changes caused by fences may confound the effects of herbivore exclusion (Daubenmire 1940; Heady 1968). Additionally, fences in subalpine and alpine areas often trap snow (Schreiner 19987), which may profoundly affect plant growth.

Table 29. Location, sample size, and general information of areas containing permanent plots.

Area	*n*	Sample years	Goat[a] removal years	C.T.'s (*n*)[b]	Site selection	Source of selected and nonselected species	Samples per year	Estimated annual precipitation (cm)
Klahhane Ridge	6	1983–86 1988 1990	1981–85 1988–89	2	Sites with high (2) and low (4) initial levels of goat use	Pfitsch and Bliss (1985)	3	110
Mount Dana	5	1984–86 1990 1992	1983 1985 1988–89	5	One plot in each of 5 community types delineated by TWINSPAN using 1983 data	Plant community survey (*n* = 189)	1	400
Avalanche Canyon	6	1988–92	1988–89	4	Sites selected to represent Avalanche Canyon area	Plant community survey plots (*n* = 16); no species fit the selected category	2	175

[a] Mountain goat (*Oreamnos americanus*).

[b] C.T.'s (*n*) = number of plant community types.

mean cover to characterize vegetation. The minimum *P*-value attainable for a comparison of treatments with two replications (i.e., high initial level of goat use at Klahhane Ridge) and four replications (i.e., low initial level of goat use at Klahhane Ridge) was 0.0667, so we used 0.10 as the critical *P*-value. In the special instance where comparisons were between two treatments with two replications each, the minimum *P*-value was 0.1667, and we used 0.1667 as a significant difference, and we marked it with an asterisk (*).

Selected and nonselected forage species (Appendix A3) were determined separately for each area because forage chosen by mountain goats was known to be area specific (Chadwick 1983; Johnson 1983; see Chapter 9). There were 14 selected forage species and 16 nonselected forage species at Klahhane Ridge, 9 selected and 15 nonselected at Mount Dana, and no selected forage species at Avalanche Canyon. Goats foraged unselectively in Avalanche Canyon because most of the landscape was rock—cliffs, talus, or scree—hence there were relatively few plants to eat. We classified Avalanche Canyon plants as species grazed only for the first 2 years ($n = 21$) and species grazed throughout the study period or only during the last 3 years ($n = 21$). This classification provided groups whose response to grazing was expected to be analogous to the selected and nonselected categories.

Summer precipitation just before sampling was used as a measure of growing-season quality. July and August records from Port Angeles were used for Klahhane Ridge and Quilcene for Avalanche Canyon. June and July records from the Hoh Ranger Station were used for Mount Dana. We estimated Quilcene precipitation in 1992 with a regression based on Hoh Ranger Station data ($r^2 = 0.96$) because Quilcene records were unavailable.

Trends in Plant Cover

Approximately one-third of total plant cover ($\bar{x} = 34.4\%$) was categorized as selected or nonselected by goats at Klahhane Ridge. Mean cover of selected plant species was 9.0% and 29.7% for plots receiving (respectively) high and low initial levels of goat use. In contrast, nonselected plant species cover was 11.3% in plots with high levels of goat use and 11.0% in plots with low goat use. As goat density was reduced, cover of selected plant species in areas originally having high levels of goat use increased at a significantly faster rate (i.e., greater slope of regression) than cover of selected plant species in areas originally having low goat use ($P = 0.0667$; Fig. 36A; Table 30). Selected plant species cover also increased faster than that of nonselected plant species in plots with high initial levels of goat use ($P = 0.1667$* [special instance described in third paragraph above]) but not in plots receiving low initial levels of goat use ($P = 0.3143$). Total plant cover increased in plots with high initial levels of goat use and decreased in plots with low initial levels of use ($P = 0.0667$).

Mean cover of selected plant species increased (10.9–14.6%) as goat density was reduced in plots receiving high initial levels of goat use at Mount Dana

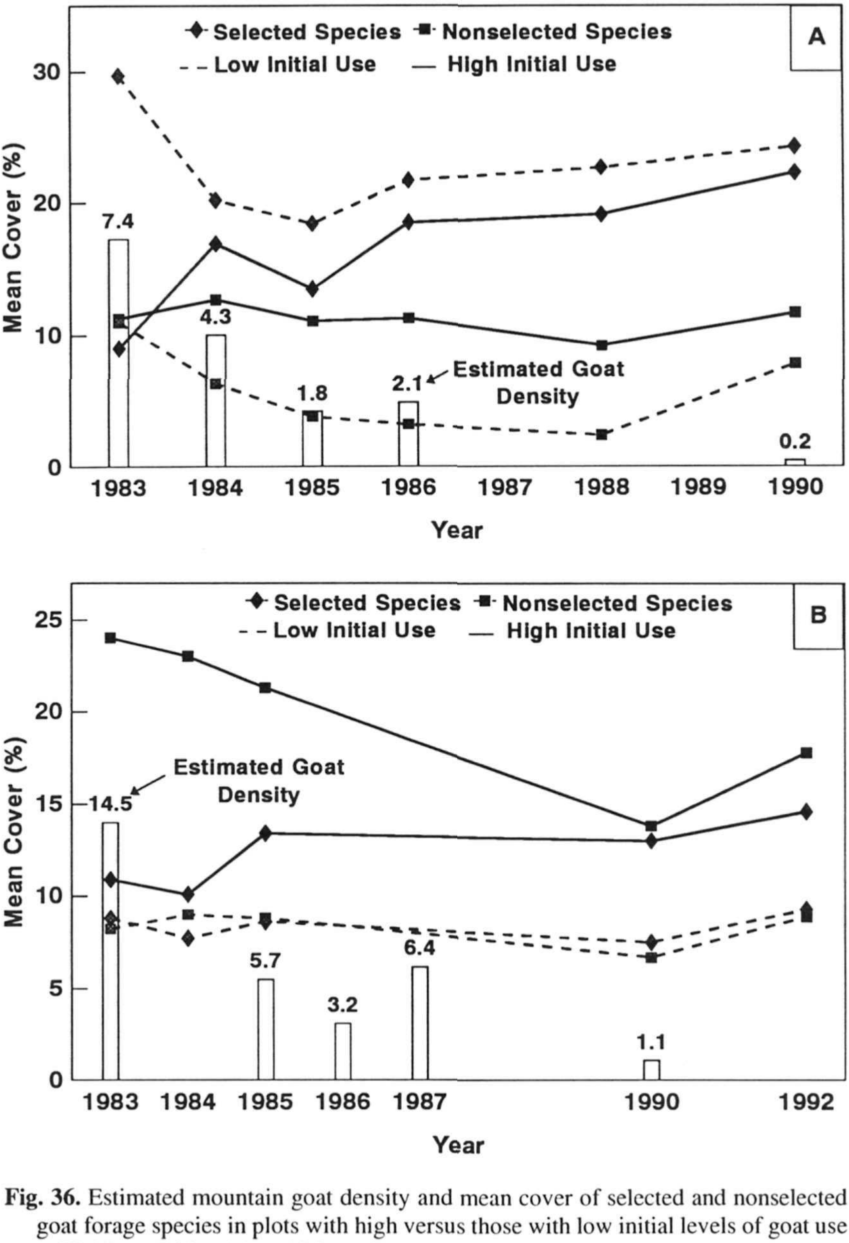


Fig. 36. Estimated mountain goat density and mean cover of selected and nonselected goat forage species in plots with high versus those with low initial levels of goat use at Klahhane Ridge (*A*) and Mount Dana (*B*).

(Fig. 36B). This contrasted significantly with a decrease in cover of nonselected plant species (24.0–17.8%; $P = 0.0970$) and total plant cover (42.1–40.1%; $P = 0.0482$) in these plots (Table 30). We did not compare cover of selected plant species in plots with high initial use versus low initial use because sample size was too small for statistical tests (i.e., selected plant species occurred in only one of two plots with low initial levels of goat use). Total plant cover and cover of

Table 30. Mean slope of regression (*b*) of mean plant cover over time and mean correlation coefficients (*r*) of mean cover with estimated mountain goat (*Oreamnos americanus*) density. Goat density estimates in 1983 and 1990 did not correspond with 1988–1992 vegetation sampling in Avalanche Canyon, so the correlations between plant cover and goat density could not be determined.

	Klahhane Ridge		**Mount Dana**	
Treatment Species group	Slope (*b*)	Correlation with goat density (*r*)	Slope (*b*)	Correlation with goat density (*r*)
Low initial goat use				
Selected species[a]	–0.25[b]	0.50[c]	0.04	0.17
Nonselected species	–0.31	0.23	–0.07	–0.20
Total cover	–0.42[d]	0.53[e]	–0.87	0.39
High initial goat use				
Selected species	1.56[b,j]	–0.84[c]	0.45[f,g]	–0.69[h,i]
Nonselected species	–0.15[j]	–0.17	–1.02[f]	0.53[h]
Total cover	2.80[d]	–0.87[e]	–0.61[g]	0.50[i]

	Avalanche Canyon
Treatment Species group	Slope (*b*)
Declining use	
Grazed first 2 years	1.82[k]
Grazed throughout	0.24[k,l]
Total cover	4.35
Stable or increasing use	
Grazed first 2 years	1.02
Grazed throughout	2.00[l]
Total cover	4.04

[a] No statistical comparisons were made with selected species in low intitial goat use plots at Mount Dana because sample size was too small.

[b,c,...,i] Significantly different at $P \leq 0.10$ using a nonparametric permutation test (Mehta et al. 1988).

[j,k,l] Significantly different at $P \leq 0.17$ (permutation test)—this was the minimum possible *P*-value given the sample size.

nonselected plant species were not significantly different between those plots with high and those with low initial goat use.

Avalanche Canyon data were compared using plots with decreasing goat use versus plots with stable or increasing goat use (Fig. 37) because all plots had high initial levels of goat use (i.e., there were no areas with low goat use). We compared species grazed only in the first 2 years of the study with those that were grazed throughout or only during the last 3 years of the study. Species grazed initially in the study were expected to increase, and those grazed later were expected to decline. Plant cover of species grazed only the first 2 years increased faster than species grazed throughout or late in the study ($P = 0.1667^*$) in plots experiencing declining goat use. These two groups were not significantly different from each other in plots with stable or increasing use.

Goat Density, Precipitation, and Plant Cover

Cover of selected plant species was negatively correlated with goat density in plots receiving high initial levels of goat use at Klahhane Ridge and Mount Dana (Table 30). The correlation coefficients between selected plant species cover and goat density in plots with high versus low initial goat use were significantly different at Klahhane Ridge ($P = 0.0667$)—sample size was too

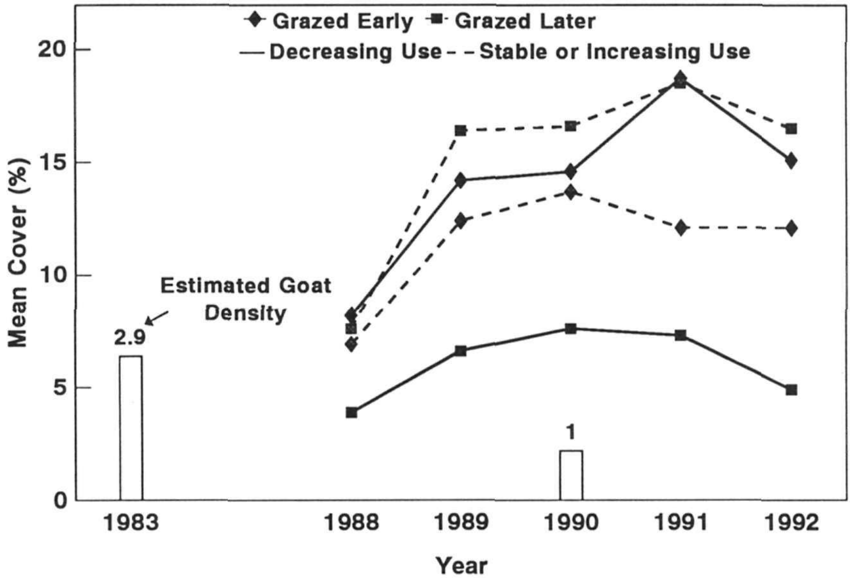


Fig. 37. Estimated mountain goat density and mean cover of plants grazed early (1988–89) and later (1988–92 or 1990–92) in plots with decreasing versus those with stable or increasing levels of goat use at Avalanche Canyon.

small to perform the test on data from Mount Dana. The correlations of nonselected plant species cover and selected plant species cover with goat density were significantly different at Mount Dana ($P = 0.0188$) but not on Klahhane Ridge. There were no differences between the correlations of nonselected plant species cover and goat density in high versus low initial use plots at Klahhane or Dana. Goat density estimates in the Avalanche Canyon area (1983, 1990) did not correspond with years of vegetation sampling (1988–92) so the association between goat density and plant cover could not be determined.

Total plant cover in plots receiving high initial levels of goat use was negatively correlated with goat density and positively correlated with density in plots with low initial levels of goat use on Klahhane Ridge ($P = 0.0667$). The correlation between goat density and total cover at Mount Dana was positive in high and low initial-use plots. Correlations using Avalanche Canyon plots were not possible (see above).

Correlation coefficients between summer precipitation and plant cover were not significantly different among treatments within study areas (Table 31). Correlations between precipitation and cover at Mount Dana were not consistent among treatments—two were positive and four were negative. Summer precipitation at the Hoh River (34 km distant at low elevation) may not have reflected growing

Table 31. Correlation coefficients (r) between mean plant cover and summer precipitation just before the sample period.

Treatment Species group	Klahhane Ridge (1983–90)	Mount Dana (1984–92)
Low initial goat[a] use		
Selected species	0.32	−0.37
Nonselected species	0.29	0.02
Total cover	0.61	−0.02
High initial goat use		
Selected species	0.14	0.13
Nonselected species	0.39	−0.61
Total cover	0.25	−0.31
	Avalanche Canyon (1988–92)	
Declining goat[a] use		
Grazed first 2 years	0.82	
Grazed throughout	0.46	
Total cover	0.48	
Stable or increasing goat use		
Grazed first 2 years	0.44	
Grazed throughout	0.54	
Total cover	0.58	

[a] Mountain goat (*Oreamnos americanus*).

season quality for Mount Dana because mean cover declined substantially in 1990 even though summer rainfall that year was the highest during the study.

Plant Community Responses

The plots used to study vegetation response to lowered mountain goat density represented seven plant communities. Klahhane Ridge plots (6) were all classified as *Phlox–Festuca* (one also fit the unstable herb–meadow community of Pfitsch and Bliss 1985). Each plot at Mount Dana (5) represented a different community (*Phlox–Carex phaeocephala*, *Phlox–Festuca*, *Phlox–Pachistima, Carex spectabilis–Lupinus latifolius*, and *Phyllodoce empetriformis*) and four communities were represented by the six plots in Avalanche Canyon (*Phlox–Pachistima*, one; *Phlox–Festuca*, one; *Phacelia*–scree, three; and *Delphinium*– scree, one). Community types were replicated within each treatment at Klahhane Ridge but not at Mount Dana or Avalanche Canyon. Consequently statistical analyses were possible only with Klahhane Ridge data.

Festuca idahoensis and *Achillea millefolium* were major constituents of the plant communities at Klahhane Ridge. They have a competitive relation mediated by herbivory—that is, *A. millefolium* dominated when *F. idahoensis* was grazed, and *Festuca* dominated when neither was grazed (del Moral 1985). *Festuca idahoensis* increased in plots where goat use was originally high and decreased in plots where use was originally low (significantly different slopes at $P = 0.0667$; Fig. 38). *Achillea millefolium* decreased in plots with high initial goat use but not in low initial use plots ($P = 0.0667$). Also, percent cover of *A. millefolium* was positively correlated with goat density in high use plots, which differed from correlations in low use plots ($P = 0.1667$*). This contrasted with the negative relation between *F. idahoensis* cover and goat density in plots receiving high initial goat use. Correlation coefficients between *F. idahoensis* cover and goat density in high versus low use plots also were significantly different ($P = 0.0667$).

The relative abundance of plant species at Klahhane Ridge changed over time in plots receiving high initial goat use but not in those receiving low initial use. For example, the disturbance-oriented *A. millefolium* dominated a high initial use plot (~10% cover) in 1983 and *Cirsium edule* and *Phlox diffusa* codominated with about 6% cover each. By 1990, *Cirsium* and *Phlox* shared dominance (~9% cover) and *F. idahoensis* had ~7% cover; *Achillea* had decreased to about 6%. A similar pattern of change occurred in the other plot with high initial use, but different species were involved. Relative cover among species in the four plots with low initial goat use remained essentially constant (Schreiner et al. 1993). Plant relative abundance in the high use plots seemed to be approaching that of the low use plots toward the end of the study.

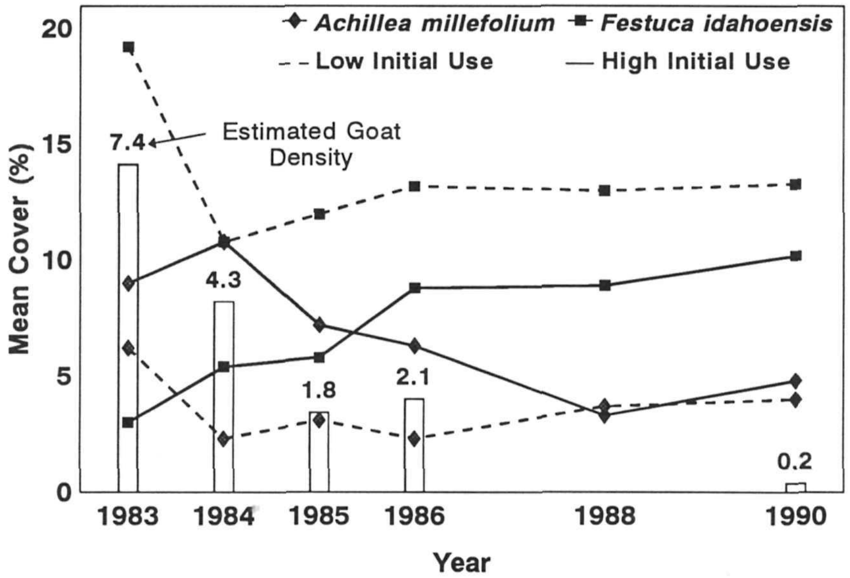


Fig. 38. Estimated mountain goat density and mean cover of *Achillea millefolium* and *Festuca idahoensis* in plots with high versus those with low initial levels of goat use at Klahhane Ridge.

We noted similar trends in behavior among several plant species at Mount Dana across community types (Schreiner et al. 1993). For example, three selected forage species (*Carex spectabilis*, *Juncus parryi*, and *Aster paucicapitatus*) occurred in three different communities and each increased in mean cover. By contrast, the disturbance-oriented *Lupinus latifolius* decreased by half or more in two high initial-use communities where it occurred. These changes modified relative abundance among codominant species in the three communities that received high initial levels of goat use. Similar changes did not occur in the two communities receiving low initial levels of goat use. Relative abundance of species in Avalanche Canyon did not change consistently within treatments or species groups.

Interpretation

Our results demonstrated that subalpine and alpine vegetation responded to lowered goat density in both the climatically wet and dry regions of Olympic National Park. As groups, selected goat forage species increased and nonselected forage species decreased as goat density was reduced. The selected and nonselected goat forage species groups (46 species total) each included bunchgrasses, shrubs, and taprooted forbs as well as rhizomatous forbs, grasses, and sedges. Caughley (1970a) reported analogous changes in plant cover following introduction of a mountain ungulate but for only eight forage species.

The reduction in goat density at Avalanche Canyon was insufficient to induce a pronounced response in vegetation, in contrast to results from the other two study areas. Goat density was only reduced from an estimated 3 to 1 goat/km^2 in the Avalanche Canyon area. This compares to reductions of from 7 to 0.2 goat/km^2 at Klahhane Ridge and from 14.5 to 1.1 goats/km^2 at Mount Dana. Additionally, there was evidence that effective goat density did not change in Avalanche Canyon. Five goats grazed in permanent plots as we sampled them in 1992, even though 12 goats were removed from the general area during 1988–89.

Subalpine and alpine vegetation of the Olympic Mountains is characterized by plant communities shaped by soil moisture availability and level of disturbance (Belsky and del Moral 1982; del Moral 1983b; Pfitsch and Bliss 1985; Appendix A2). Our results confirm the importance of disturbance (i.e., herbivory) in controlling the relative abundance of plant species at high elevations (>1,520 m). Individual disturbance-oriented plant species decreased and selected plant species increased as levels of disturbance (goat density) were reduced. These changes took place in sparsely vegetated plant communities on unstable substrates as well as those dominated by shrubs, forbs, and sedges on comparatively stable substrates. We interpret this to mean that goats caused increased disturbance in a wide variety of plant communities, irrespective of species composition. The null hypothesis that plant relative abundance would not respond to changes in mountain goat density was rejected.

The effects demonstrated here of goats on vegetation occurred mainly on summer ranges where resources (i.e., plants) were unlikely to limit the population (Pfitsch and Bliss 1985; Houston and Stevens 1988). Goat effects on winter range, especially on cliffs and rock outcrops where plant cover is extremely low, could have been even more dramatic.

Chapter 11. Photographic Comparisons: A Qualitative Appraisal of the Influence of Climate and Disturbances on Vegetation, 1915–1990

E. G. Schreiner and J. E. Burger

In the previous chapter we described how vegetation responded quantitatively to decreasing mountain goat density from 1983 to 1992. Photographs taken before goats were introduced compared with repeat photographs taken later allowed us to extend the evaluation of vegetation in relation to mountain goat herbivory further back in time—albeit qualitatively. We report results from an ongoing study of long-term changes in subalpine vegetation; photographs from Klahhane Ridge are presented because we have not completed work elsewhere in the park. Our objective was to characterize historic changes in vegetation and soils with respect to climate, disturbances (such as fire and windthrow), mountain goats, and humans.

Photographs were selected for picture quality and age rather than preconceptions that a repeat photograph would produce a specific result. Poor focus was the main reason photographs were rejected, but some pictures were not used because the view was too distant or too hazy for changes to be observed or because we could not locate the site. Several visits to a given site were sometimes required to obtain the best correspondence of plant phenology and snow patch patterns. Dominant plant species were recorded at the time scenes were rephotographed.

Our general approach was to compare photographs taken before goats were introduced or when they were at low density with photographs taken when density was high. Later, photographs taken when density was high were compared to those taken after the Klahhane Ridge goat subpopulation was reduced. We compared general features, including aspect, type of view (distant, moderately distant, close), plant community type(s), and noted whether or not the scene was the same as that shown in other pairs. Differences (if any) in each community were described and then tallied as increases, decreases, or no changes in vegetation, amount of exposed soil, and goat sign (Appendix A1). The term *community view* refers to individual communities within a picture and *photographic pair* refers to pictures of the same landscape taken at two different times. Plant community names follow those of Pfitsch and Bliss (1985) and Appendix A2. Forces driving changes included goats, humans, fire, and climate change, or combinations thereof. Interpretations are conservative; unless a single cause of change was clearly identifiable (e.g., fire), all contributing factors were considered.

Sixty-six photographic pairs illustrated landscape changes from 1915–20 to 1990. This interval covers the time before goats were introduced through the subpopulation peak in the late 1970's to 1990 when only a few goats remained. Comparisons cover about 4.7 km^2 from about 1,400 to 1,900 m elevation. Eleven scenes are presented; the remainder are available in Olympic National Park files (J. E. Burger, Klahhane Ridge comparison photographs, Olympic National Park, unpublished report). The photographic comparisons document changes primarily on goat summer range; we have no comparisons from lower-elevation winter ranges.

Climate and Fire

During 1915–90, periods of low summer precipitation (July–August) occurred in 1915–29, 1941–45, 1957–60, 1968–73, and 1980–86 (see Fig. 4). Snowpack fluctuations did not parallel summer precipitation. For example, from 1968 to 1973, a relatively high April snowpack was followed by low summer precipitation. At Hurricane Ridge, April snowpack began to decline in 1949, reached a 30-year low in 1979–80, and has remained low since. Mean July–August temperature increased fairly rapidly (from ~12 to 14° C) from 1910 to 1925, continued a more gradual increase to around 1960, and fluctuated near 15° C from around 1960 to 1990.

Plant succession induced by climate change was visible mainly on north-facing slopes initially photographed around 1915–40 (Plate 1). Heath–shrub communities dominated by *Phyllodoce empetriformis* and *Cassiope mertensiana* were invaded by subalpine fir, especially in concave landscapes where snow accumulates (Plate 2). Herbaceous vegetation increased in some sites with late-melting snow and stayed remarkably unchanged in others (Plate 3). No tree invasion was observed in the drier ridge-top fellfield (Plate 4), unstable herb meadow, or *Phlox–Festuca* communities. The results of forest succession following fires are visible in several photographs (Plate 5).

Mountain Goats

Modifications of vegetation and soils by mountain goats were visible even though goat effects were superimposed on those driven by climate, fire, and humans. Effects were most visible on south- and east-facing slopes and seemed to be influenced by goat density. Comparisons were made during 3 periods of differing goat density: 1981–82, just after peak goat densities; 1985–86, medium density (following removal of 181 goats); and 1990, low density (following more removals, an estimated three goats remained).

Photographic pairs of the 1950's through the 1970's compared with 1981–82 in unstable herb meadow, ridge-top fellfield, and *Phlox–Festuca* communities consistently showed increased bare mineral soil, reduced total plant cover, formation of wallows, and an increase in the number of trails (Plates 6–9). Three of four views of scree slopes from the 1960's showed an increase in the number of wallows or the formation of new trails. Of the 30 plant-community views in these pictures, 11 (37%) showed no change, 14 (47%) showed reduced total plant cover, and 10 (3%) had more bare mineral soil (Table 32). These changes were attributable to goats in 12 (40%) instances, to natural events in 11 (37%), and to a combination of natural events and goats or people in 5 (17%).

The 1985–86 retakes produced more variable results (Table 32) because time intervals differed considerably (i.e., 5–70 years). Goat density at the time the initial photographs were taken ranged from zero (pre-goat) to the highest recorded (late 1970's; Houston and Stevens 1988); density declined from 1981 to 1984. Nearly half of the plant community views (42%) showed no change—a few showed tree invasion (17%). Scenes from the 1960's compared with 1985–86 showed increased bare soil. Those from the 1970's compared with 1985–86 tended to show a decrease in the number of wallows and that the mineral soil component (fines) at the surface of wallows had disappeared from scree slopes (Plate 10). An increase in total plant cover was often observed in the 1985–86 photographs compared with those from 1981 to 1982.

Short-term comparisons of the 1981–82 and 1985–86 photographs with those of 1990 (Table 32) showed that vegetation evidently responded to reduced goat density. Increased total plant cover was visible in all 10 views. Three of the 10 views showed a decrease in disturbance-oriented plant species, and 7 showed an increase in the abundance of *Festuca idahoensis*. Nine of 10 views exhibited a decrease in the amount of bare ground, which suggested that substrates had become less disturbed. Changes were attributed to reduced goat density in 8 of the 10 views.

Mountain goats were observed using small rocky outcrops on south-facing slopes among stands of subalpine fir when goat density was high (Plate 11). Even though goats regularly used north-facing slopes among subalpine fir during summer hot spells, they infrequantly used south slopes among the trees (Stevens 1979). The level of use on south-facing rocky outcrops among the trees, however, was sufficient to cause a substantial reduction in plant cover. One such rocky outcrop at midslope south of Klahhane Ridge exhibited dramatic recovery between 1980 and 1986 (Plate 11). Increased cover on this site occurred sooner than other, more preferred, sites. This outcrop was evidently among the first to be abandoned by goats as densities were lowered, hence the rapid recovery. Species exhibiting increased cover included *Artemisia ludoviciana* and *Bromus sitchensis.*

Changes in which major plant community components such as *Artemisia ludoviciana* were greatly reduced or eliminated by herbivory are best illustrated by Plate 9 beginning in 1970. These comparisons of an unstable herb meadow community showed loss of the *Artemisia* by 1982, continued absence (or cover so

Table 32. Changes in vegetation and soils between photographic pairs. Results represent the number of times a change was observed for each plant community type within a photographic pair.

		Vegetative changes[a]										
	Views	No	Trees		Total		Dist. spp.		Stable spp.		Shrubs	
Year	(*n*)	change	+	–	+	–	+	–	+	–	+	–
Comparisons with 1981–82												
1950's	1	–	–	–	–	1	–	–	–	–	–	–
1960's	19	10	2	1	1	7	–	1	–	–	1	1
1970's	10	1	1	–	3	6	2	1	–	1	2	–
Total	30	11	3	1	4	14	2	2	–	1	3	1
% of total		37	10	3	13	47	7	7	–	3	10	3
Comparisons with 1985–86												
1915–20	12	4	7	–	1	–	–	–	–	–	1	–
1940's	5	1	3	–	1	–	–	–	–	–	–	–
1950's	7	–	1	1	–	4	1	–	–	–	1	1
1960's	10	4	1	–	–	1	–	1	–	1	1	–
1970's	13	8	–	1	2	–	2	–	–	1	–	–
1981–82	25	13	–	–	8	2	1	–	2	–	–	–
Total	72	30	12	2	12	7	4	1	2	2	3	1
% of total		42	17	3	17	10	6	1	3	3	4	1
Comparisons with 1990												
1980–81	5	–	–	–	5	–	–	1	4	–	–	–
1985–86	5	–	–	–	5	–	–	2	3	–	1	–
Total	10	–	–	–	10	–	–	3	7	–	1	–
% of total		–	–	–	100	–	–	30	70	–	10	–

[a] Vegetative changes represent no change in the plant community or increases(+) or decreases (–) in cover of trees, total plants, disturbance-oriented species, species that represent stable soils, and shrubs—by each community in the view.

(*Table continues next page*)

low it is virtually undetectable) in 1985, and its reappearance in 1990, when an estimated three goats remained. This type of change might be attributed to annual variations in weather except that (1) the photographs span seasons of both high and low precipitation (*Artemisia* was abundant in 1970, a dry summer following wetter summers, and was greatly reduced by 1982, which was also a dry summer following wetter summers); (2) permanent-plot data did not show the wholesale loss of *Artemisia* that would be expected if weather were the cause (Schreiner 1987); and (3) *Artemisia* remained undetectable in the 1985 Plate 9 photograph even though it had reappeared by 1985 in another Klahhane Ridge site (i.e., in another location, *Artemisia* was undetectable in 1980 and reappeared in 1985 along with several other species because effective goat density had been reduced there earlier [see Plate 11]). In other words, *Artemisia* cover seemed to reflect goat

Table 32. *Continued.*

	Soil changes[b]													
No	Bare soil		Fine soil		Wallows		Trails			Causes[c]				
change	+	–	+	–	+	–	+	–	Erosion	G	P	N	GP	N+GP
(Comparisons with 1981–82)														
–	1	–	–	–	–	–	–	–	–	1	–	–	–	–
6	7	–	1	–	1	–	2	–	2	6	–	7	1	3
3	2	–	–	1	–	–	–	–	3	5	–	4	1	–
9	10	–	1	1	1	–	2	–	5	12	–	11	2	3
30	33	–	3	3	3	–	7	–	17	40	–	37	7	10
(Comparisons with 1985–86)														
7	–	3	–	–	–	–	1	–	1	1	–	10	–	1
3	–	1	–	–	1	–	–	–	–	–	–	4	–	1
1	4	–	–	–	1	–	1	–	–	4	–	2	1	–
4	4	–	1	–	–	–	1	–	1	2	2	2	4	–
5	–	2	–	4	1	4	–	1	–	7	–	4	1	1
9	1	5	–	1	1	–	–	1	3	11	–	4	3	4
29	9	11	1	5	4	4	3	2	6	25	2	26	9	7
40	13	15	1	7	6	6	4	3	8	38	3	36	13	10
(Comparisons with 1990)														
–	–	5	–	1	–	–	–	–	–	5	–	–	–	–
1	–	4	–	1	–	–	1	–	2	3	–	–	1	1
1	–	9	–	2	–	–	1	–	2	8	–	–	1	1
10	–	90	–	20	–	–	10	–	20	80	–	–	10	10

[b] Soil changes represent no changes in the plant community or increases (+) or decreases (–) in bare mineral soil exposure, amount of fine soil material visible, number of wallows, number of trails, and if erosion was visible—by each plant community in the view.

[c] G = goats; P = people; N = natural events; GP = goats and people; and N+GP = natural events and goats or people.

densities rather than weather or snowpack patterns. This view is consistent with the finding of Pfitsch and Bliss (1985) who noted that *Artemisia* was a preferred forage of mountain goats.

Interpretation

The analysis of photographic pairs expanded our understanding of vegetation dynamics on Klahhane Ridge in time and space. We observed no changes in plant communities typified by late-melting snow (usually with *Antennaria lanata* or *Carex nigricans*). Impressive numbers of *Abies lasiocarpa* invaded *Phyllodoce empetriformis* meadows. Plant succession following fire was evident in some scenes but did not seem to play a major role in vegetative changes of nonforested areas. Drier communities on south slopes exhibited decreases followed by increases in plant cover that was inverse to mountain goat density. The results of human trampling were also evident, often in combination with vegetative and soil alterations associated with mountain goats.

Tree invasion into heath communities, as observed on Klahhane Ridge has been reported throughout western North America (Rochefort et al. 1994). Brink (1959) reported massive invasions of *Abies lasiocarpa* and *Tsuga mertensiana* into meadows of the coastal mountains of British Columbia, Canada, from 1920 to 1940; invasions also occurred from 1919 to 1950 in the Cascade Mountains of Washington (Franklin et al. 1971b; Lowery 1972; Henderson 1974; Heikkinen 1984). Tree incursions into subalpine meadows elsewhere in the Olympic Mountains occurred during 1923–60 (Fonda and Bliss 1969; Kuramoto and Bliss 1970; Agee and Smith 1984). However, a recent study of invasions of *A. lasiocarpa* at Heather Park (see Plate 2) showed that most tree invasion took place considerably later (1945–84) than that reported elsewhere (A. Woodward and E. Schreiner, unpublished manuscript, College of Forest Resources, University of Washington, Seattle). Invasion of trees into many subalpine meadows has been correlated with changing temperature and snowpack (Rochefort et al. 1994).

The photographs allowed us to record changes in goat summer range that were not measured in permanent plots. For example, we saw a major shift in the relative abundance of rocks and bare mineral soil in goat wallows. Active wallows on scree had mineral soil at the surface that was no longer visible after goats stopped using them. The long-term ramification of this may be to change the course of plant succession because the ability of seeds to germinate is closely linked to substrate type (e.g., organic matter, mineral soil) and particle size distribution (Harper 1977). We are unable to predict the consequences of substrate changes, but the senior author has observed that the dominant vegetation of scree and talus slopes elsewhere in the Olympics seemed to be controlled by the size of particles in the substrate.

Plant communities on southern exposures, ridge tops, and scree slopes of Klahhane Ridge have evidently started to return to the plant composition that occurred before the high density of goats was present. Photographs from before, during, and after the peak of goat density in the late 1970's exhibit trends in plant cover consistent with this hypothesis. Plant species such as *Festuca idahoensis*, a bunchgrass often consumed by goats, decreased as goat density increased and then increased as goat density decreased. By contrast, disturbance-oriented species such as *Achillea millefolium* increased as goat density increased and decreased as goat density decreased. We do not have quantitative measurements of vegetation change as goat density increased, but qualitative changes observed as goat density declined parallel those measured in permanent plots. Photographic comparisons, then, also

Plates

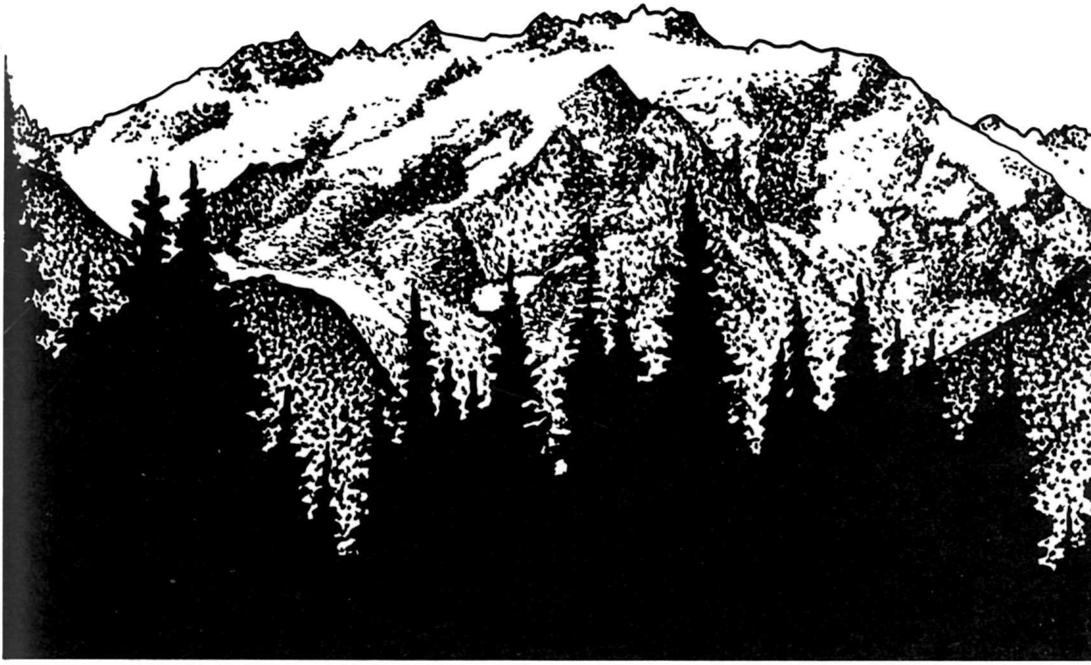


PLATE 1

Location

View to the northwest of Heather Pass–First Divide and First Top, from the ridge east of Second Top (elevation 1,798 m)

Photographers

E. B. Webster (R. Dalton collection), circa 1915–20's (from B/W copy neg.)
J. Burger, 19 July 1986 (50-mm lens on Technical Pan)

Vegetative changes

Interval of circa 65–70 years

Middleground and background

The formerly bare slope in the center and right foreground is now being invaded by *Abies lasiocarpa* and *Lupinus latifolius*. However, the late snowmelt area at the lower left corner is still bare. *Abies lasiocarpa* have not become established in the area of the pass where snags persisted in the Webster photograph. The maintained trail is visible by 1986. The forested areas around the pass are more dense, but this seems to be caused by individual tree growth rather than by establishment of new trees.

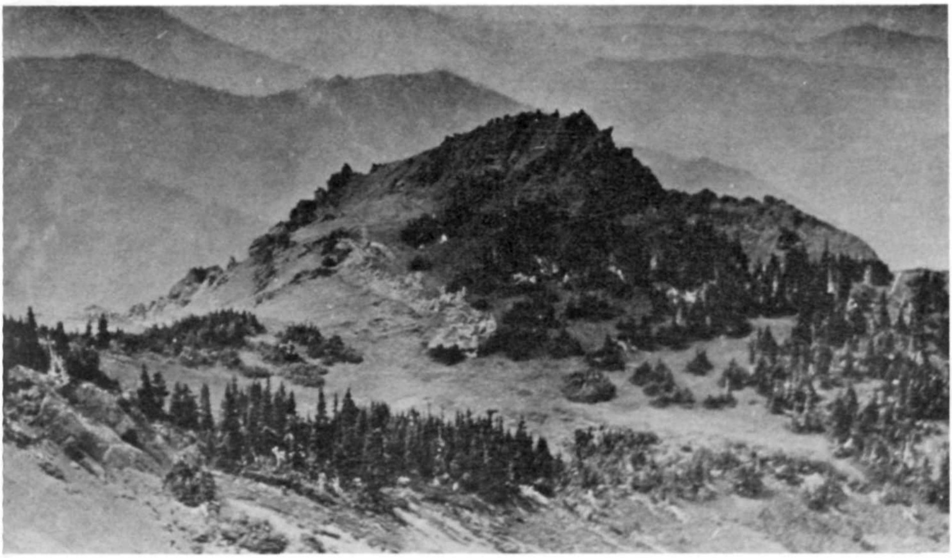


PLATE 2

Location

Ed Webster and the view of the cirque north of Second Top (the peak south of Heather Pass–First Divide) taken from the trail east of the pass (elevation 1,675 m)

Photographers

T. Chambers collection, circa 1915–20's (from B/W copy neg.)
J. Burger, 19 July 1986 (28-mm lens on Technical Pan)

Vegetative changes

Interval of circa 65–70 years

Foreground and middleground

The meadow has been invaded by *Abies lasiocarpa* and *Lupinus latifolius*. The solifluction lobes are no longer visible (though the increased plant cover may obscure them). By 1986, *Abies lasiocarpa* was also established in formerly bare areas in the upper meadow. The maintained trail is visible in the lower right corner of the 1986 image.

Background

The far, late-snowmelt slope is still bare. Though a series of years with light snowpack probably allowed the tree establishment in the meadow, this area evidently received enough snow to prevent tree invasion.

PLATE 3

Location

Klahhane Ridge, about 1 km east of Klahhane Saddle; view east toward Rocky Peak (elevation 1,860 m)

Photographers

G. Fagerlund, 2 September 1956 (from ONP 2 1/4 neg. #3433)
J. Burger, 23 August 1986 (28-mm lens, on Technical Pan)

Vegetative changes

Interval of 30 years

Foreground and middleground

The trail is new, but the meadow vegetation of *Carex* spp. and *Antennaria lanata* seems unchanged. Some of the *Abies lasiocarpa* in the background have died. The dead ones are close to the trail (*right clump*) or near a trail frequently used by goats (*left clump*).

PLATE 4

Location

View to the northeast from the slope just north of Heather Pass/First Divide with the lowlands around Sequim in the background (elevation 1,722 m)

Photographers

E. B. Webster (R. Dalton collection), circa 1915–20's (from B/W copy neg.)
J. Burger, 19 July 1986 (50-mm lens on Technical Pan)

Vegetative changes

Interval of circa 65–70 years

Foreground and middleground

Because the original photograph is slightly fuzzy, it is difficult to make exact comparisons. The foreground has large clumps of *Potentilla fruticosa* in 1986 that weren't evident in the original. However, the small, dark plant clumps visible in the original are no longer present. The only other change is the *Abies lasiocarpa* growth.

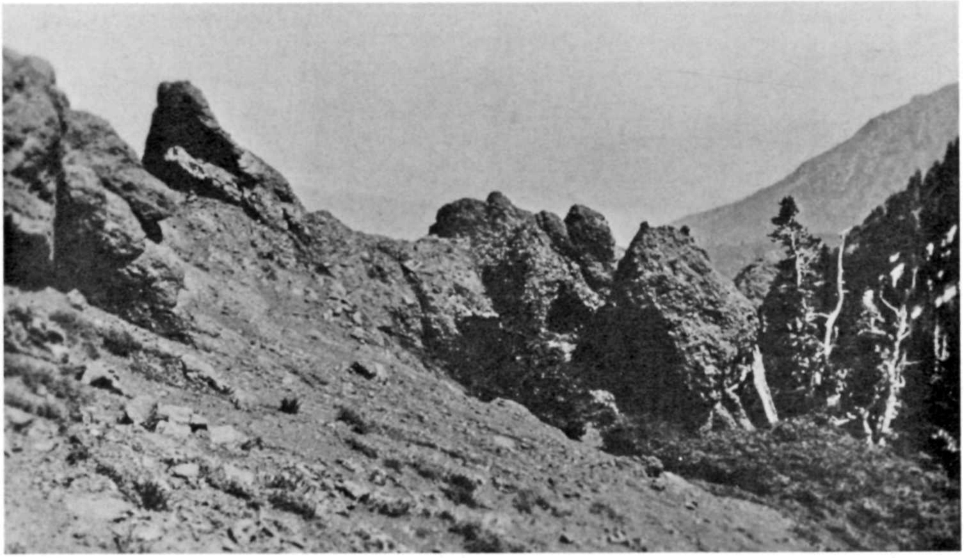


PLATE 5

Location

Klahhane Ridge, view to the northwest over the meadow where the trail begins its descent toward Lake Angeles with the rocky shoulder of Second Peak in the background (elevation 1,798 m)

Photographers

C. N. Webster, circa 1940 (from B/W neg.)
J. Burger, 24 August 1985 (50-mm lens, from color)

Vegetative changes

Interval of circa 45 years

Middleground and background

By 1985, there is more bare ground along the lip of the meadow. On the left edge of the 1985 photograph, a wallow is visible. There has been considerable regrowth among the burned snags both on the meadow lip and in the far right background burn.

PLATE 6

Location

North side of Klahhane Saddle, about 5 m out on trail toward Heather Park (elevation 1,798 m)

Photographers

J. W. Thompson (#1), 1960–64 (from color)
D. B. Houston, 12 August 1981 (from color)

Vegetative changes

Interval of circa 20 years

Though the phenology seems relatively similar, there are some differences in the abundance of flowers.

Foreground and middleground

There are fewer flowering plants evident in 1981 (primarily *Phlox diffusa*, *Penstemon davidsonii*, and *Erigeron compositus*), and there is a general decrease in plant cover.

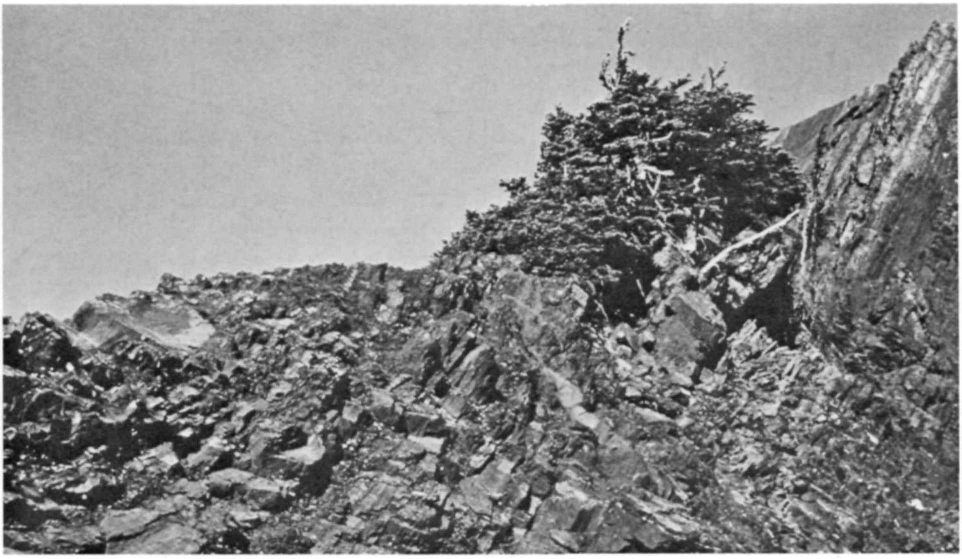


PLATE 7

Location

View of large blowout site on Klahhane Ridge, just east of where trail turns north to descend to Lake Angeles; view east from southeast of trail along the ridge crest (elevation 1,830 m)

Photographers

L. Lack (#2), June 1962 (from color)
D. B. Houston, 21 August 1981 (from color)

Vegetative changes

Interval of 19 years

This bare area may not have been started by goats, but heavy goat use exacerbated the damage by wallowing, removing plant cover, and increasing the area's susceptibility to wind erosion.

Middleground and background

By 1981, the middle and upper left of the blowout have eroded deeper and larger with whole clumps of turf gone. The smaller, bare areas to the left of the large one also eroded more deeply. There are wallows visible on the center right slope in 1962; by 1981, this area seems to have less plant cover, and some disturbed patches are still visible. The juniper clumps along the right edge are smaller, and one is no longer visible.

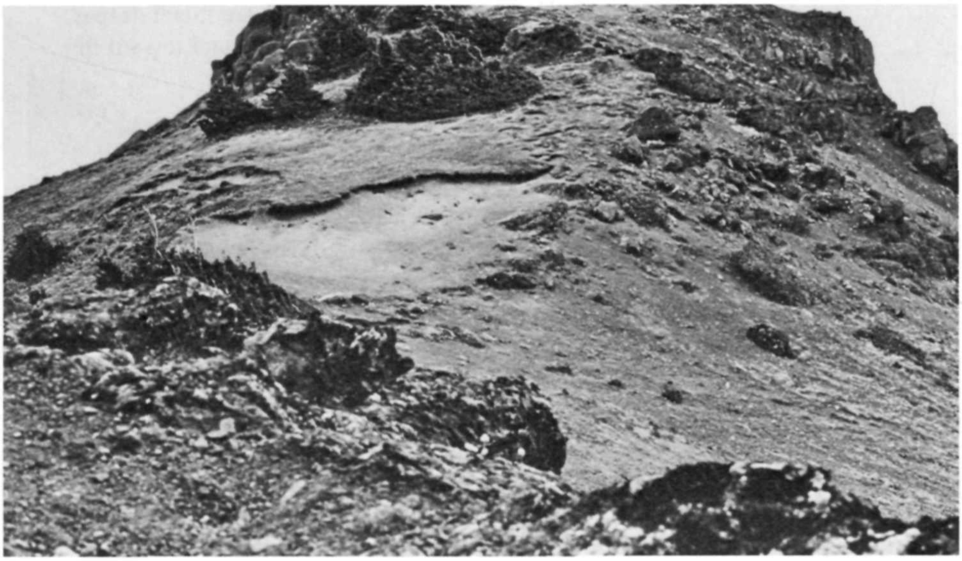


PLATE 8

Location

View of slope above (east of) large blowout site on Klahhane Ridge, just east of where trail turns north to descend to Lake Angeles (elevation 1,830 m)

Photographers

L. Lack (#4), 31 August 1964 (from color)
D. B. Houston, 21August 1981 (from color)

Vegetative changes

Interval of 17 years (also see Plate 7 for overall view)

Foreground and middleground

The whole area has less plant cover and much more churned-up bare ground by 1981. The wallows on the left are much deeper, and new wallows developed along the left edge and toward the center. There is an increase in *Achillea millefolium*.

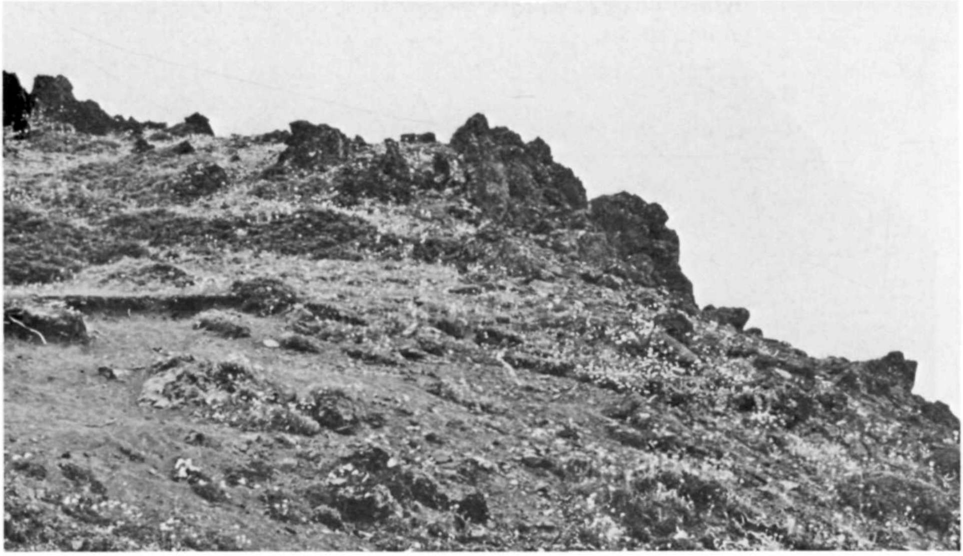


PLATE 9a

Location

Klahhane Ridge, view of the east-facing slopes of the cirque north of Klahhane Saddle, from just below the trail circa 100 m before the trail begins switchbacks up to Second Divide (elevation 1,675 m)

Photographers

B. Moorhead (#1), 27 August 1970 (from color)
D. B. Houston, 12 August 1981 (from color)

Vegetative changes

Interval of 11 years

Foreground and middleground

There is a marked decrease in the plant cover, especially the light-colored *Artemisia ludoviciana*, on the middle and foreground slopes.

Background

There is less plant cover on the far slope above and below the trail.

PLATE 9b

Location

Klahhane Ridge, view of the east-facing slopes of the cirque north of Klahhane Saddle, from just below the trail circa 100 m before the trail begins switchbacks up to Second Divide (elevation 1,675 m)

Photographers

D. B. Houston, 12 August 1981 (from color)
J. Burger, 6 August 1985 (50-mm lens, from color)

Vegetative changes

Interval of 4 years

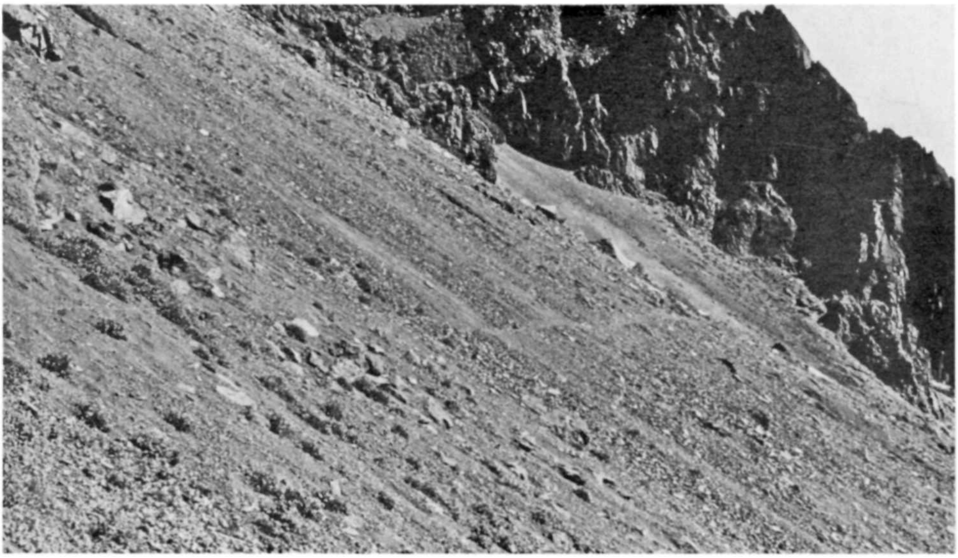
The Klahhane Ridge goat population was drastically reduced.

Foreground and middleground

There seems to be a slight increase in plant cover on the middle and foreground slopes, though this may be caused by a difference in phenology making the plants look more robust.

Background

There is no evident change.



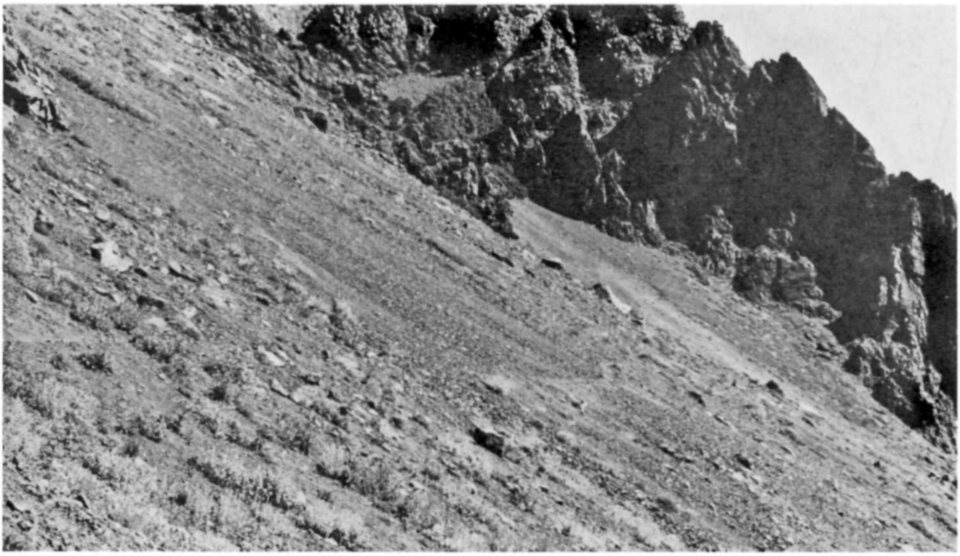


PLATE 9c

Location

Klahhane Ridge, view of the east-facing slopes of the cirque north of Klahhane Saddle, from just below the trail circa 100 m before the trail begins switchbacks up to Second Divide (elevation 1,675 m)

Photographers

D. B. Houston, 12 August 1981 (from color)
J. Burger, 1 August 1990 (50-mm lens on Pan-X)

Vegetative changes

Interval of 9 years

The Klahhane Ridge goat population was virtually eliminated.

Foreground and middleground

There is an increase in plant cover on the middle and foreground slopes (primarily *Artemisia ludoviciana*, *Phacelia hastata*, and *Cirsium edule*).

Background

There is increased plant cover above and below the trail on the center right slope.

PLATE 10

Location

View of the slope above the Klahhane switchback trail circa 30 m before the saddle (elevation 1,792 m)

Photographers

D. Pike, 30 June 1978 (from color)
J. Burger, 15 July 1985 (50-mm lens, from color)

Vegetative changes

Interval of 7 years

The goat population on Klahhane Ridge was reduced by about 80%.

Foreground

Areas below the rock along the right edge and along the left edge have more plant cover by 1985, mostly *Achillea millefolium* and grasses. This may be partially due to phenologic differences. Notice the large difference in proportion of fine soils between the two photographs. The bottom photograph shows rock (talus size) compared to finer fragments in the top image.

PLATE 11

Location

The Klahhane Switchback trail, four switchbacks above the junction with the Hurricane Ridge trail; view to the southwest (elevation 1,675 m)

Photographers

M. Hutchins, July 1980 (from color)
J. Burger, 15 July 1986 (50-mm lens on Plus-X)

Vegetative changes

Interval of 5 years

The Klahhane goat population was reduced by approximately 80%. Though the foregrounds match well, it was difficult to match the perspective; Hutchins probably used a short telephoto lens. Note that because people shortcut the trail switchback in front of the center rock, this area is not likely to recover completely, even in the absence of goats.

Foreground and middleground

The phenology is later, but there is an obvious increase in plant cover by 1985, mostly *Cirsium edule*, *Artemisia ludoviciana*, *Hydrophyllum fendleri*, *Phacelia hastata*, and grasses.

Background

Plant cover on the rocky outcrop increased.

caused us to reject the null hypothesis that reducing mountain goat densities will not result in changes to the relative abundance of plant species. Moreover, photographic comparisons documented changes in the relative abundance of plant species as mountain goat densities increased.

Chapter 12. Rare Plants

E. G. Schreiner, M. B. Gracz, T. N. Kaye, A. Woodward,
and N. M. Buckingham

Rare plants—about 9% of the ~1,200 native vascular flora—contribute measurably to the biodiversity of the Olympic Peninsula. The Washington State Natural Heritage Program lists 395 vascular plant species and varieties as rare in Washington State (Washington Natural Heritage Program 1990)—106 (27%) of these occur on the Olympic Peninsula, an area representing less than 8% (13,800 km^2) of the surface area of the state. Olympic National Park has an even higher concentration of these plants with 77 species (19%) on just over 2% (3,700 km^2) of the state.

Concern for the rare flora of Olympic National Park resulted from the discovery that some endemic plants[15] were consumed by mountain goats. Pike (1981) found that three endemics exhibited increased standing crop when they were protected from ungulates in goat summer range. Fragments of the endemic *Campanula piperi* were also detected in goat fecal samples (see Chapter 6). The detection of this species in goat diets was remarkable because of the plant's limited occurrence and low standing crop. Additionally, direct observations and permanent plots indicated that goats consumed and sometimes wallowed on the endemic *Astragalus australis* var. *olympicus*.

To assess the risk posed by mountain goats to the long-term persistence of rare plants, we (1) made a thorough search of several herbaria for records of plant locations, (2) compiled information from historical and modern plant lists, (3) examined all sample plot data for the presence and location of the Washington Natural Heritage Program plants, (4) conducted a survey for rare plants at high elevations, and (5) studied the habitat requirements and demography of *Astragalus australis* var. *olympicus*.

Distribution of Rare Plants

Rare plants listed by the Washington Natural Heritage Program occurred throughout the Olympic Peninsula (Fig. 39). Most taxa were evidently rare locally—30 were known from only 1 area and 12 from only 2 areas on the peninsula. Particularly high concentrations of rare plants occurred near sea level at Lake Ozette (14) and at high elevations in the northern and northeastern part

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[15] See Chapter 3 for a discussion of endemism and a complete list of endemic taxa.

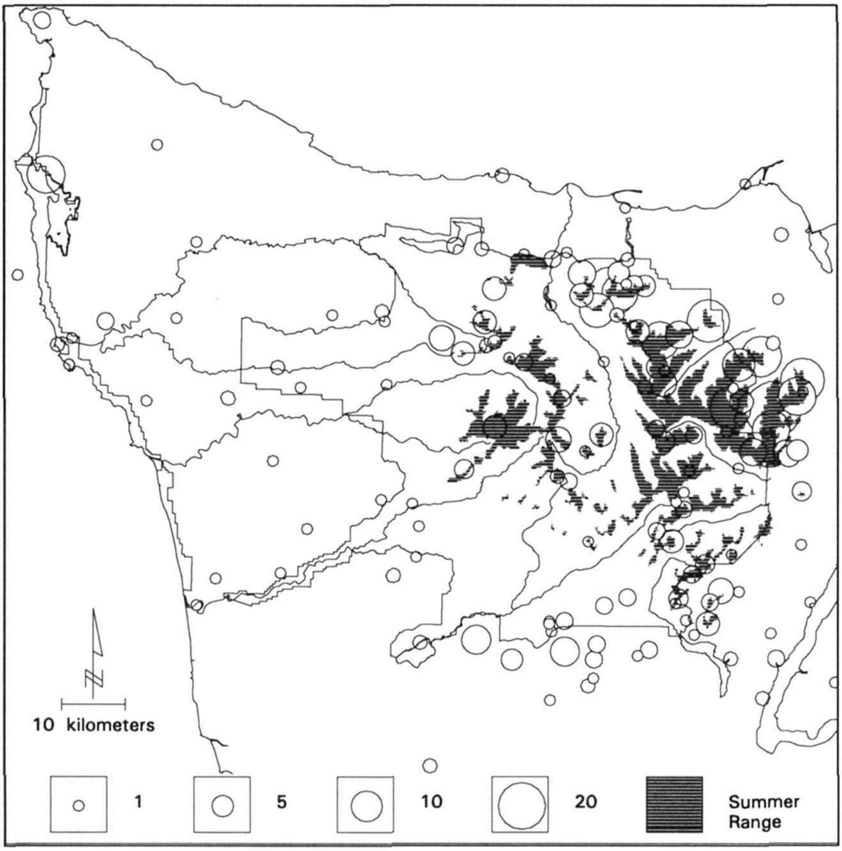

Fig. 39. Locations of rare vascular plants listed by the Washington Natural Heritage Program (1990) in relation to mountain goat summer range. Circles are proportional to the number of taxa in each area.

of the peninsula: Mount Angeles (22), Elk Mountain (14), Blue Mountain (17), Royal Basin (16), and in the Buckhorn Mountain region (26) on Olympic National Forest.

The elevation distribution of rare plants was bimodal (Fig. 40A). Thirty-eight taxa had average elevations below 305 m, 27 between 305 and 1,520 m, and 37 greater than 1,520 m. Forty-three percent of the 77 rare plants found in the park occurred within mountain goat summer range (i.e., average elevation above 1,520 m; Table 33). Nine high-elevation taxa were known from only one park location, and 17 occurred at 5 or fewer sites in the park. Seven of the eight Olympic Peninsula endemics had average elevations between 1,500 and 1,870 m, and one, *Erigeron peregrinus* ssp. *peregrinus* var. *thompsonii*, occurred at low

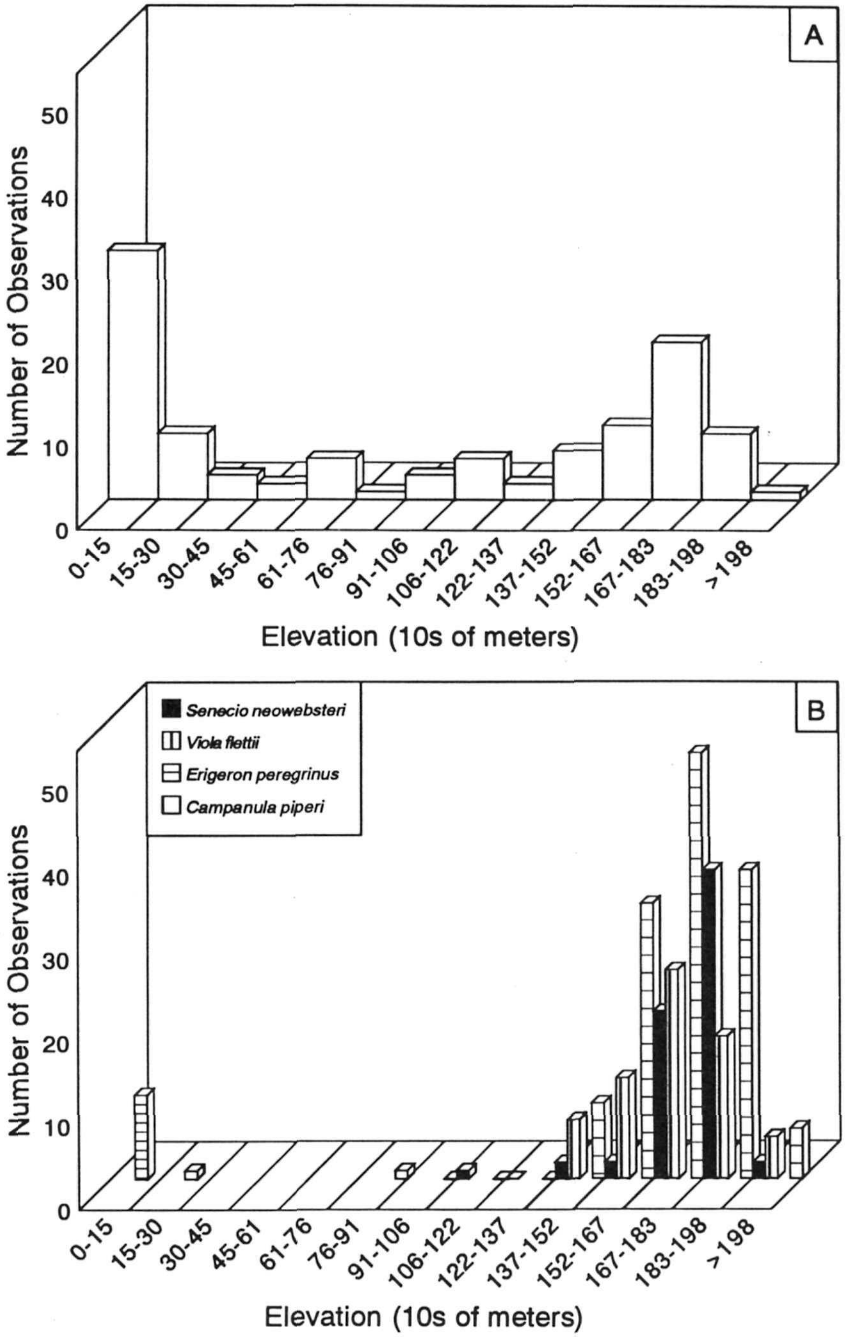

Fig. 40. Elevation distribution of rare plants on the Olympic Peninsula. *A* = taxa listed by the Washington Natural Heritage Program (1990); *B* = selected taxa endemic to the peninsula.

Table 33. Olympic Peninsula vascular plants listed by the Washington Natural Heritage Program (WNHP; 1990) that have average elevations within mountain goat (*Oreamnos americanus*) summer range in Olympic National Park (ONP).

Species (WNHP status)[a]	Total[b]	Average elevation (m)	P[c]	B[c]	O[c]	U[c]
Species known from 5 or fewer ONP locations						
Botrychium lunaria (3)	1	1,768	1	0	0	0
Douglasia nivalis var. *dentata* (4)	1	1,829	1	0	0	0
Salix brachycarpa ssp. *b.* var. *b.* (4)	1	1,905	1	0	0	0
Dryas drummondii var. *d.* (3)	1	2,057	1	0	0	0
Pellaea breweri (3)	2	1,631	1	0	1	0
Poa rupicola (4)	2	1,846	1	0	1	0
Botrychium pinnatum (3)	3	1,591	1	0	2	0
Carex obtusata (3)	5	1,800	1	0	4	0
Zigadenus elegans ssp. *e.* (4a)	6	1,795	1	0	5	0
Poa suksdorfii (4)	3	1,788	2	0	1	0
Saxifraga debilis (3)	3	1,798	2	0	1	0
Erigeron flettii (4)[d]	19	1,580	2	3	14	0
Phlox hendersonii (4)	10	1,908	4	0	6	0
Lloydia serotina ssp. *s.* (4)	11	1,676	4	0	7	0
Astragalus australis var.[d] *olympicus* (2)	5	1,554	4	0	1	0
Asplenium viride (4)	8	1,696	5	1	2	0
Saxifraga tischii (4a)[e]	8	1,856	5	1	2	0
Species known from 6 or more ONP locations						
Oxytropis viscida var. *v.* (3)	6	1,734	6	0	0	0
Poa arctica ssp. *grayana* (3)	8	1,539	6	0	2	0
Arnica nevadensis (4)	10	1,759	8	1	1	0
Salix arctica (4)	10	1,789	8	0	2	0
Poa paucispicula (4)	10	1,687	9	0	1	0
Carex raynoldsii (4)	11	1,667	6	0	5	0
Synthyris pinnatifida var. *lanuginosa* (3)[d]	14	1,867	8	1	5	0
Arnica rydbergii (4)	16	1,676	10	0	6	0
Geum triflorum var. *campanulatum* (4)	18	1,654	11	0	7	0
Erigeron compositus var. *discoideus* (4)	18	1,784	13	0	0	5
Senecio neowebsteri (4)[d]	23	1,824	16	1	6	0
Orthocarpus imbricatus (4)	24	1,683	16	1	6	1
Viola flettii (4)[d]	36	1,751	19	3	13	1
Petrophytum hendersonii (4)[d,f]	46	1,500	24	2	17	3
Campanula piperi (4)[d]	47	1,698	27	4	16	0
Aster paucicapitatus (4)[e]	47	1,574	34	1	11	1

Table 33. *Continued.*

Species (WNHP status)[a]	Total[b]	Average elevation	P[c]	B[c]	O[c]	U[c]
Pedicularis bracteosa var. *atrosanguinea* (4)[e,g]	4	1,547	4	0	0	0
Species that may occur in ONP						
Senecio lugens (4)	8	1,769	0	1	7	0
Draba longipes (3)	1	1,890	0	1	0	0
Species not known to occur in ONP						
Draba cana (3)	1	1,829	0	0	1	0
Astragalus microcystis (3)	2	1,813	0	0	2	0

[a] Washington Natural Heritage Program categories: (2) threatened; (3) sensitive; (4) monitor; and (4a) monitor for listing.
[b] Total = number of areas where the plant is known to occur on the Olympic Peninsula.
[c] P = number of known Olympic National Park locations; B = number of known locations on the border with the park (i.e., may or may not be in the park); O = number of known locations outside the park; U = precise location unknown (e.g., Clallam County).
[d] Olympic Peninsula endemic.
[e] Olympic Peninsula–Vancouver Island endemic.
[f] We listed this species as occurring in goat summer range because it occurs mainly on rocky outcrops.
[g] Incomplete data.

elevations (Fig. 40B). Additionally, three of the Olympic Peninsula–Vancouver Island endemic taxa had average elevations higher than 1,520 m.

Rare Plants and Mountain Goats

Goat censuses showed that goat summer range overlapped rare plant distributions (Fig. 39). Evidence of mountain goat use was still visible in 1988 and 1990 even though the goat population had decreased from an estimated 1,175 ± 171 (SE) in 1983 to 389 ± 106 animals in 1990. Twenty-one of 22 areas surveyed contained rare plants, and all areas exhibited evidence of mountain goats (see Chapter 9). However, the extent of herbivory by mountain goats on rare plants was difficult to assess because so few rare taxa occurred in plots.

Grazing on two endemic taxa, *Aster paucicapitatus* and *Astragalus australis* var. *olympicus*, was attributed to mountain goats (Table 34). *Aster paucicapitatus* was grazed in 12 of the 18 plots where it occurred in Royal Basin, a medium goat density area, but was not grazed in the 21 low-density-area plots at Grand Pass. Because deer and marmot signs were encountered in both areas and goat sign was far more prevalent at Royal Basin than Grand Pass (see Table 24), goats were implicated as responsible for the grazing (elk sign was not observed in either area). *Aster paucicapitatus* was one of 33 species considered to be forage selected by mountain goats (see Table 27). Numerous goat wallows,

Table 34. Average grazing, plant and grazing frequency, and species relative grazing frequency (SRGF) of rare vascular plant taxa listed by the Washington Natural Heritage Program (1990) in subalpine plots of Olympic National Park.

	Average grazing (%)			Frequency (*n*)										
				Plant			Grazing			SRGF			SRGF ratios	
Species	H	M	L	H	M	L	H	M	L	H	M	L	H/L	M/L
Aster paucicapitatus[a]	4.7	1.6	0.1	77	25	25	33	14	1	42.9	56.0	4.0	10.7	14.0
Senecio neowebsteri[b]	0.2	T	0.7	5	6	15	1	2	2	20.0	33.3	13.3	1.5	2.5
Orthocarpus imbricatus	T	0.0	0.0	9	8	11	2	0	0	22.2	0.0	0.0	∞	0.0
Astragalus australis[b]		0.6			76			19			25.0			
Pedicularis bracteosa[a]	T			6			2			33.3				
Petrophytum hendersonii[b]	T	0.0	0.0	8	1	3	1	0	0	12.5	0.0	0.0	∞	0.0
Campanula piperi[b]	0.0	0.0	0.0	5	33	17	0	0	0	0.0	0.0	0.0	0.0	0.0
Geum triflorum	0.0	0.0	0.0	1	8	6	0	0	0	0.0	0.0	0.0	0.0	0.0
Viola flettii[b]	0.0	0.0	0.0	1	8	12	0	0	0	0.0	0.0	0.0	0.0	0.0
Erigeron flettii[b]	0.0			2		1	0		0	0.0		0.0	0.0	
Phlox hendersonii			0.0			1			0			0.0		
Botrychium lanceolatum	0.0			1			0			0.0				
Synthyris pinnatifida[b]		0.0	0.0		1	10		0	0		0.0	0.0		0.0
Oxytropis viscida		0.0	0.0		4	4		0	0		0.0	0.0		0.0
Claytonia lanceolata[c]	0.2	0.0	0.0	48	1	4	9	0	0	18.8	0.0	0.0	∞	
Erigeron compositus[c]	T	T	0.0	3	44	29	1	1	0	33.3	2.3	0.0	∞	∞

[a] Olympic Peninsula–Vancouver Island endemic species.

[b] Olympic Peninsula endemic species.

[c] One variety of these species is listed by the Washington Natural Heritage Program—varietal name of the plants in the plots was unknown.

tracks, and pellet groups in plots containing *Astragalus australis* var. *olympicus* indicated that mountain goats grazed this species. *Astragalus* was grazed in all three medium-goat-density areas where it occurred.

Fourteen other rare taxa were found in plots used to describe subalpine and alpine plant communities (Table 34) but were not sufficiently abundant to make an evaluation of goat effects on them. *Campanula piperi*, for example, occurred in only 5 plots in high, 33 plots in medium, and 17 plots in low goat density areas. The plants were not grazed in any area, which may indicate that *Campanula* was nonselected by goats or that we did not have enough plots in high density areas to detect grazing.

Similarly, permanent plots in the three areas where goat densities were reduced (see Chapter 10) contained four rare plant taxa. However, these too were so infrequent that the effects of goat herbivory could not be established (Schreiner et al. 1993).

Astragalus australis var. *olympicus*: A Case Study

Astragalus australis var. *olympicus* is a rare endemic known only from the dry northeastern Olympic Mountains. The metapopulation of 3,800–4,000 individuals occurs at 1,525–1,825 m in Olympic National Park as 11 subpopulations (Kaye 1989).[16] Habitat includes south-facing subalpine talus, windswept ridges, and knolls on calcium-bearing substrate. This taxon is listed as threatened by the Washington State Natural Heritage Program (1990) as well as a Category 1 candidate for the federal endangered species list (U.S. Fish and Wildlife Service 1993). Observations of mountain goat grazing, trampling, and wallowing in *A. australis* var. *olympicus* subpopulations prompted concern for the well-being of this plant.

Astragalus australis var. *olympicus* or its precursor may have reached the Olympic Mountains from the north. The distribution of *A. australis* is similar to that of another Olympic Mountain rare plant, *Oxytropis viscida* var. *viscida*. Barneby (1964) suspected they followed the same migration routes and that both taxa reached the Olympic Peninsula via Beringia and then south during a Pleistocene interglacial period. *Astragalus australis* var. *olympicus* probably did not arrive here by long-distance dispersal; the closest population of *A. australis* var. *glabriusculus* (the nearest relative of *A. australis* var. *olympicus*) is about 500 km distant in northeastern Oregon.

Isolation in the Olympic Mountains left a population of *A. australis* with unique traits. The inflated seed pod of var. *olympicus* sets it apart from var. *glabriusculus*, though the pods of some Alaskan forms also are "decidedly tumid" (Barneby 1964). Although var. *olympicus* has not been isolated long enough to evolve into a separate species, as have some other Olympic endemics, the distinct inflated pods could represent an important dispersal adaptation. Seeds from flat pods can be expelled explosively, be eaten, or simply drop from the plant, but inflated legume pods can also be dispersed by wind (Ridley 1930). With further isolation, this variety may evolve into a separate species, as speciation through reproductive isolation is fairly common in montane floras (Hickman 1968; Favarger 1972; Ives 1974; Stebbins 1982). *Astragalus australis* var. *olympicus* and associated species fit rather loosely into the cushion plant community described by Kuramoto and Bliss (1970). Species common to cushion plant communities and often found growing with *Astragalus* included *Phlox diffusa*, *Festuca idahoensis*, *Allium crenulatum*, and *Lomatium martindalei* (Kaye 1989). Kaye (1989) identified seven plant community types with *Astragalus* as a constituent. A feature held in common at all sites was calcareous substrate with pH almost always over 6.

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[16] A new subpopulation outside the park was recently (July 1992) discovered in the Mount Townsend area on Olympic National Forest.

Population Dynamics and Goat Effects

Intensive sampling of the physical and biological environment of *Astragalus* subpopulations was conducted at Blue Mountain and Mount Angeles where most of the plants occurred (Appendix A1). Plots were located in areas of physical site homogeneity that included at least one *Astragalus* individual and were distributed over the range of environmental conditions observed in each plant subpopulation. Ten plots were permanently marked, all *Astragalus* plants were mapped and counted, and grazing or physical injuries were noted from 1985 to 1991. Plots were distributed as follows: Unicorn Peak (2), Griff Peak (1), Blue Mountain (5), and Hurricane Hill (2). All mountain goats were eliminated from Blue Mountain, and goat density was reduced by 98% at Mount Angeles during 1981–89.

We counted 1,442 *Astragalus* individuals (36% of the estimated population) in 79 plots. Permanent plots revealed that the *Astragalus* subpopulations were more or less stable from 1985 to 1991 (Fig. 41) and that seedling establishment was highest in 1990 and 1991 (Fig. 42). Seedling mortality was about 50% per year in 1987–88 and 1990–91.

Mountain goat sign was found inside and adjacent to plots established in *Astragalus* subpopulations (Table 35). *Astragalus* was grazed in more than half of the subpopulations. Goat activity was particularly evident in the Mount Angeles *Astragalus* subpopulations, where sign was found inside or near 70% of the plots even though the goat population there had been substantially reduced.

Permanent plots showed that *Astragalus* plants were injured (grazed or trampled) by goats. Injury was sporadic but sometimes intense (Fig. 43). Some injuries were obviously caused by goats (i.e., abundant goat sign adjacent to grazed or trampled *Astragalus* plants), but the cause of other injuries could not be determined. Goat wallowing in three plots was responsible for four dead plants in 1986. Extensive grazing and trampling of plants at Unicorn Peak in 1987 were entirely attributable to mountain goats. In the plots where most of the injuries took place, 26 of 50 subplots contained goat tracks. Grazing was evident on 72% (89) of the

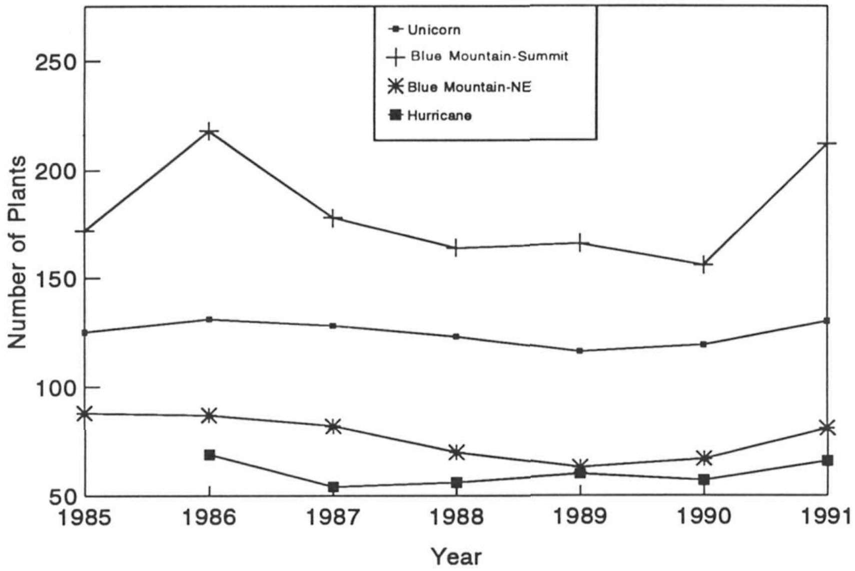

Fig. 41. Total nonseedling *Astragalus* individuals in plots within four subpopulations.

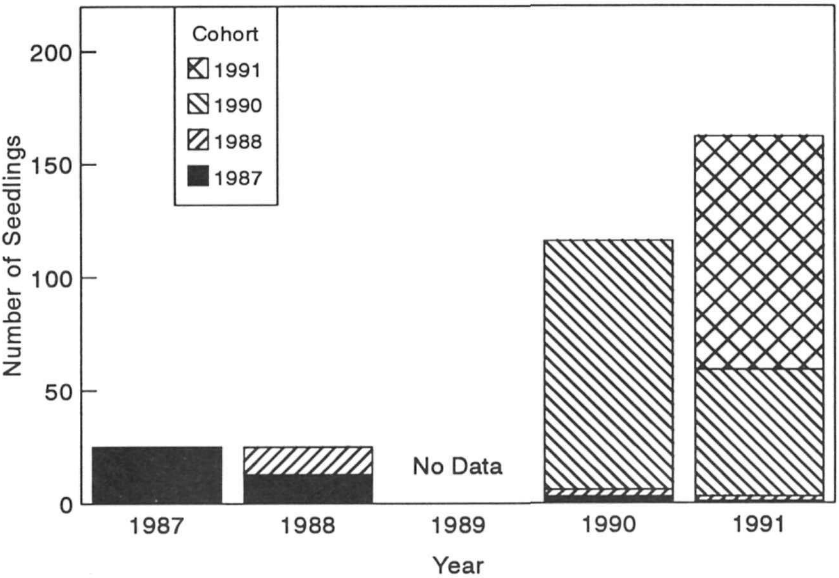

Fig. 42. Total *Astragalus* seedling establishment and cohort survival in plots within four subpopulations.

Table 35. Evidence of mountain goat (*Oreamnos americanus*) use in and around plots established in subpopulations of *Astragalus australis* var. *olympicus*, 1985–1986.

Subpopulation name	Plots	Wallows within 50 m of plot	Pellet groups inside plots	Plots with grazing on *Astragalus*
Blue Mountain				
Summit	6	10	9	0
Northeast	21	7	0	3
Mount Angeles				
Northwest	17	27	0	8
First Top	6	0	3	0
Heather Park	6	1	0	3
Second Top	14	31	10	3
Unicorn/Griff Peak	3	11	0	2
Hurricane Hill	6	0	0	1
Total	79	87	22	20

individuals in the plots—most were noted as 76–100% grazed. Goats evidently moved through the area and stopped to graze and wallow in the *Astragalus*.

Astragalus *Habitat*

We performed three analyses to determine how much *Astragalus* habitat was present and how much was occupied in Olympic National Park. First, 687 of the plots used to describe subalpine and alpine vegetation[17] (including 79 with *Astragalus*) were classified into communities based on plant cover (Appendix A1). Second, we employed nonparametric discriminant analysis to classify plots by similarities among environmental variables (e.g., slope, aspect, and rock fragment size). The plant community classification was then compared to the classification based on environmental variables. Agreement between these two classifications (i.e., plots were placed in similar groups by environmental- and plant-based methods) was assumed to mean that environmental variables adequately explained the plant community classification. We further assumed that if the plant-based classification grouped the plots that contained *Astragalus,* then a distinct set of environmental variables represented *Astragalus* habitat. Consequently, if the classification using environmental variables also grouped *Astragalus* plots, then *Astragalus* habitat was probably represented by that group of environmental variables. Finally, we used logistic regression to determine which environmental

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[17] Plots used in these analyses did not include those established in 1988 and 1990—hence the number of plots does not match those in Chapter 9.

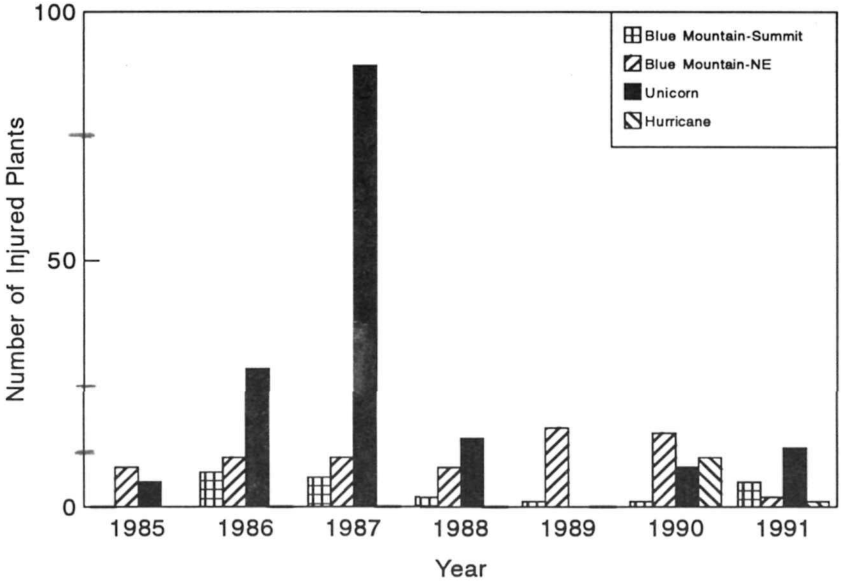

Fig. 43. Total number of grazed or trampled *Astragalus* in plots within four subpopulations during 1985–91.

variables contributed most to explaining differences between plots containing *Astragalus* and those that did not.

The plant community classification resulted in four major groups that were readily discernible on the basis of plant composition—one group was com posed entirely of *Astragalus* plots.[18] The four groups reflected the importance of moisture and disturbance levels to subalpine community composition (Kuramoto and Bliss 1970; Pfitsch and Bliss 1985). All plots at the dry extreme (44) contained *Astragalus*, a slightly wetter group contained 44% (35) of the *Astragalus* plots, and 284 additional plots were dominated by species such as *Phlox diffusa* and *Festuca idahoensis*. Two groups were dominated by *Carex spectabilis*, *Phyllodoce empetriformis*, or *Cassiope mertensiana*.

Astragalus habitat was limited in extent and may have been fully occupied. Discriminant analysis based on environmental variables classified *Astragalus* plots in groups that were comparable to the groups produced by the classification based on plant cover. The two methods classified 84% of the *Astragalus* plots similarly. Only 16% of the plots that did not contain *Astragalus* were classified by the discriminant analysis as having environmental conditions potentially suitable for *Astragalus*. Plots that lacked *Astragalus* but had *Astragalus*-like habitat occurred in wetter areas of the park (i.e., well outside the dry northeastern Olympic Mountains where the *Astragalus* occurs) and were apparently unsuitable or too distant for propagules to reach.

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[18] See Appendix A2 for a more detailed discussion of subalpine plant communities.

Environmental variables determined by the logistic regression to be most important in distinguishing *Astragalus* plots were slope, aspect, percent cover of bare mineral soil, total rock, and the cover of rocks in the >2-mm–4-cm size-class. Average slope of *Astragalus* plots was 28°, aspect averaged 201°, bare mineral soil averaged 11.9%, and average total rock cover was 81.9%. Average cover of rocks in the >2-mm–4-cm size-class was 56.3%.

Blue Mountain plots contained an average of 3 times more *Astragalus* plants per square meter than did plots representing Mount Angeles subpopulations (1.01 vs. 0.31; $P < 0.01$, Mann–Whitney *U*-test). The logistic regression equation describing *Astragalus* habitat characteristics was used to test the hypothesis that habitat differences were responsible for different densities of plants between the two areas. Based on habitat characteristics, the equation predicted that the mean probability of a plot containing *Astragalus* at Blue Mountain was 0.47 and 0.53 at Mount Angeles ($P = 0.40$, Mann–Whitney *U*-test). The major difference between the two areas was the historical density of mountain goats (much greater on Mount Angeles) rather than habitat characteristics.

Interpretation

These preliminary investigations of rare plants in the presence of mountain goat herbivory were inconclusive. Rare plants in the park are indeed rare—some occur in just one site, others occur as a few widely-spaced individuals. Our studies demonstrated that there is considerable overlap between mountain goat summer range and the habitat of rare plants. Even though we were unable to quantify the risk mountain goats pose to the persistence of rare plant populations, it is clear that mountain goats do affect and kill individual plants through grazing, wallowing, and trampling. Four endemic species were grazed by goats—one was considered a selected forage.

The *Astragalus australis* var. *olympicus* population trend shown by permanent plots represented only a short-term picture. Circumstantial evidence from habitat analysis suggested that goat herbivory may have reduced plant densities on Mount Angeles compared to Blue Mountain. Seedling establishment varied markedly among years. One or 2 years of successful seedling establishment means little to the persistence of a subpopulation or to species survival because of high mortality. Considerably longer study will be required to determine population trends. Goat effects on *Astragalus* were sporadic, sometimes intense, and had unknown long-term consequences to the survival of the species. We have insufficient data to cleanly reject the hypothesis that mountain goat herbivory does not jeopardize the persistence of rare plant populations. Enough information exists to be concerned about the long-term fate of these taxa. We do not expect goats to necessarily consume or trample the last individuals in a population of rare plants, but they may increase risk of extinction by fragmenting populations or habitats. Risk of extinction increases as populations are fragmented or reduced in number (Pimm 1991). Extinction often involves a combination of forces acting on small, fragmented populations (e.g., Interagency Spotted Owl Committee 1990). Assessment of the potential for long-term (i.e., 15–25 years or more) persistence of populations of individual taxa will require intensive study of plant demography and available habitat.

Finally, it is preposterous to expect all rare plants to respond similarly to goat herbivory. Definitions of rarity are based on abundance, habitat requirements, and distribution (Rabinowitz 1981) rather than autecological characteristics. Rare plants of the Olympic Mountains include annuals (*Orthocarpus imbricatus*), rosette-forming perennials occurring in meadows (*Geum triflorum* var. *campanulatum*), and perennials confined to rocky outcrops (*Petrophytum hendersonii*). Harper (1977), Grime (1979), and many others have expended considerable energy to demonstrate how autecological characteristics govern plant demography. This reinforces the need for long-term demographic studies of individual taxa—truly a formidable task considering the number of rare plants in the Olympic Mountains.

Chapter 13. Synthesis of Herbivory

E. G. Schreiner and D. B. Houston

Plants and herbivores are inescapably linked. The type and magnitude of the interactions between herbivores and plants depend on the food habits, behavior, and abundance of the herbivore; the growth form and physiology of the plants; and the dynamics of ecosystem processes where the herbivores and plants are both present (Harper 1977; Crawley 1983; Abrahamson 1989). Herbivore populations have direct and indirect effects on individual plants and indirect effects on plant communities and ecosystem processes (Floate 1981; Begon et al. 1986).

The direct influence of herbivores on individual plants is relatively straightforward. Plants either lose a portion of their biomass or sustain tissue injuries from being consumed or trampled (Caughley 1976b; Harper 1977; Floate 1981; Crawley 1983). Wallowing, especially by large herbivores, also may damage plant tissue; death of the plant often results when it is directly under the herbivore (Begon et al. 1986; Polley and Wallace 1986). Burrowing tends to cause root injuries, burial of plant parts, and presumably death if the plant is directly in the path of the larger burrowing animals (Platt 1975; del Moral 1984; Krueger 1986; Coffin and Lauenroth 1988; Whicker and Detling 1988).

Indirect effects of herbivores on individual plants, communities, and ecosystem processes are legion. Herbivores may alter plant growth form and reproductive output (Islam and Crawley 1983; Paige 1992) or cause individuals to produce tannins as secondary compounds to deter herbivory (Harper 1977; Rhodes 1985). Wallowing and burrowing expose bare mineral soil, which alters community composition in favor of ruderal plant species (Platt 1975; Pfitsch 1981; del Moral 1984; Polley and Wallace 1986; Whicker and Detling 1988). Relative abundance of plant species in the community may be altered because herbivores forage selectively (Ellison 1960; Anderson and Loucks 1979; McNaughton 1979; Day and Detling 1990; McInnes et al. 1992). A subtle but important effect of herbivores on ecosystem processes also results from redistribution of nitrogen in soils caused by urine and fecal deposition (Begon et al. 1986; Ruess and McNaughton 1987; Coffin and Lauenroth 1988; Day and Detling 1990; Frank and McNaughton 1992; Seagle et al. 1992). Deposition of nitrogen in feces may alter the rate nitrogen is cycled through the ecosystem, which in turn may affect the productivity of plant communities (Cargill and Jeffries 1984).

Our work demonstrated that introduced mountain goats have indirect and direct effects on the vegetation of the Olympic Mountains, a finding held in common with all other studies of ungulate grazing systems. We have no reason to believe that the general biotic effects of goats on the vegetation of the Olympics differs appreciably from mountain goat grazing systems where the animals are native. Nonetheless, changes in the park's vegetation have been substantial, and the status of rare plant populations is of concern.

Mountain goats modified the relative abundance of plants in subalpine plant communities of the Olympics; disturbance-oriented species such as *Achillea millefolium* increased with heavy grazing, and selected species such as *Festuca idahoensis* decreased. Mountain goats likely changed the competitive relations between these two species because a laboratory study demonstrated that *Festuca* was the stronger competitor except when clipped (del Moral 1985). Changes in plant cover of these two species were also visible in comparative photographs and were reported from the exclosure studies of Pfitsch and Bliss (1985) and Schreiner (1987).

Modifications of plant communities also occurred without necessarily changing competitive interactions among plant species; cover of selected and nonselected plant species changed at Mount Dana, but this did not change community dominants. Cover of dominant, strongly competitive species such as *Carex spectabilis* did not always respond to lowered goat density. This does not necessarily mean that *C. spectabilis* was unaffected by goats. *Carex spectabilis* is highly productive (Kuramoto and Bliss 1970; del Moral 1983a, 1984, 1985) and may have compensated for loss of grazed plant tissues. Graminoid species are well known for their compensatory response to grazing (McNaughton 1979; Begon et al. 1986).

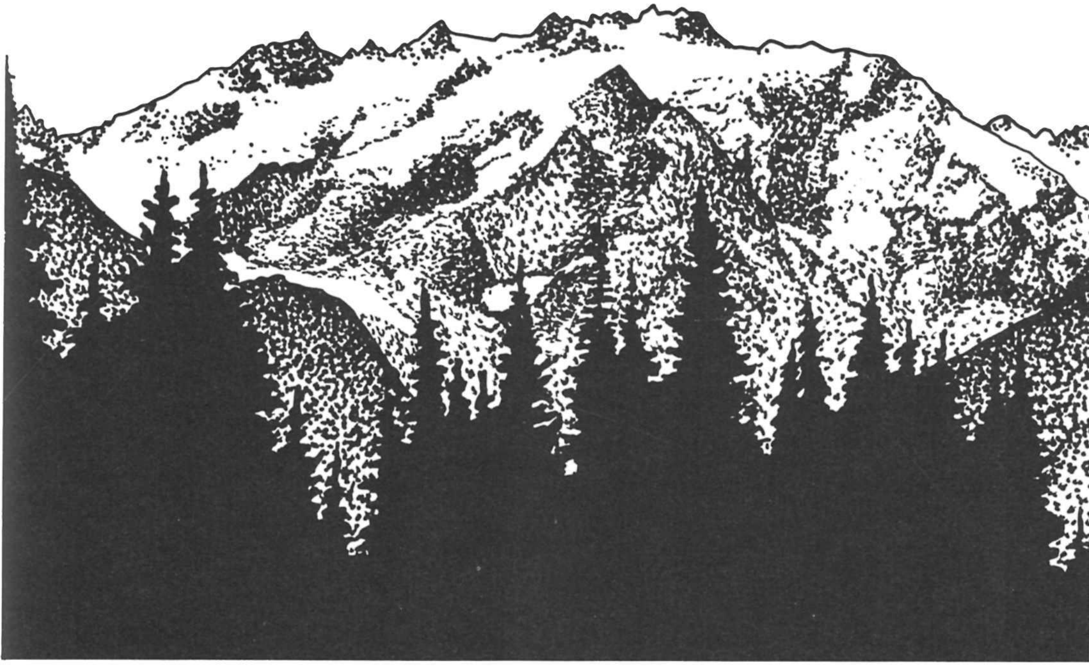
Additionally, mountain goats influenced the vegetation of Olympic National Park by wallowing. Wallows disturbed soils and created mineral substrates for colonization by plants. Studies of Klahhane Ridge goat wallows (Pfitsch 1981; Reid 1983) and bison wallows elsewhere (Polley and Wallace 1986) showed that disturbance-oriented plants dominated wallow edges and that these disturbed sites differed from surrounding vegetation. We documented presence of wallows in all study areas. On Klahhane Ridge, we noted disturbance-oriented species invaded wallow edges as they probably did elsewhere. Such a result is to be expected because Olympic subalpine and alpine plant communities are particularly sensitive to soil disturbance (Bell and Bliss 1973; Schreiner 1974; Belsky and del Moral 1982; del Moral 1984). Some investigators believe that physical disturbances associated with herbivory may be more important than grazing (Harper 1977; Floate 1981) in changing the vegetation.

Incidentally consumed forage species may suffer intensive grazing at either high (Futayama and Wasserman 1980) or low (Houston 1982) herbivore densities. These forages may be eliminated because they exert no feedback control on herbivore population size. In a hypothetical one herbivore–one plant species system, the herbivore and plant must reach a dynamic equilibrium or the herbivore goes extinct (Caughley 1982). Further, in a one herbivore–two plant system (assuming that the two plant populations have different growth rates), "The extinction of one of the two plants is a direct consequence of its sharing the area with the other. ... It goes extinct when sharing the area because the herbivore numbers and hence grazing pressure are maintained at a higher level than would be possible if the slower growing plant were the only food available" (Caughley 1982:311). Thus, rare plants may be at risk due to mountain goats for at least two reasons: (1) mountain goat population densities likely are not controlled by plant abundance on summer ranges (Houston and Stevens 1988), let alone rare plant abundance, and (2) goats are generalist herbivores with the capacity to consume most plant species, including rare plants.

We remain concerned about the long-term persistence of rare plants in mountain goat habitat. We note that the effects of goats on individual plant taxa may be severe or potentially severe, especially for taxa with very restricted distributions (i.e., those that are present in less than five subpopulations). Rare, endemic plants have been driven to extinction or near extinction elsewhere by introduced herbivores (e.g., goats in Hawaii and the Galapagos Islands; Loope et al. 1988).

Our studies represent only a small part of the total picture of mountain goat herbivory. Recent studies demonstrate that ungulates alter nitrogen cycles and soil formation processes (Day and Detling 1990; Frank and McNaughton 1992; McInnes et al. 1992). Moreover, vegetative changes wrought by one herbivore may influence the feeding behavior of other herbivores (Krueger 1986; Day and Detling 1990). Given the relations between site productivity and the degree of interspecific plant competition in Olympic subalpine vegetation (del Moral 1983a, 1985), mountain goats are likely to have a far greater influence on individual plant populations, communities, and ecosystem processes than we have demonstrated here.

Mountain Goat Management



Chapter 14. Mountain Goat Management in Olympic National Park

D. B. Houston, R. A. Hoffman, R. W. Olson, and B. B. Moorhead

The National Park Service goat management program launched in 1981 was based on several premises:

1. Mountain goats seemed to be changing the character of the park's subalpine vegetation.
2. The presence of goats and their effects on the vegetation were contrary to the congressionally mandated purpose of the park.
3. Goat removal was consistent with established policy on management of exotic species.
4. The time frame for defining exotic species by National Park Service policy had been tested in court with the Grand Canyon National Park burro issue (see Introduction).

Goat management during the 1980's occurred in two phases: an experimental management program (EMP) initiated under the 1981 environmental assessment (National Park Service 1981), with aspects continuing through 1987, and an operational management program (OMP) initiated in 1988 under provisions of the 1987 environmental assessment (National Park Service 1987) and originally scheduled to run through 1992. Both environmental assessments were prepared in compliance with National Environmental Policy Act (NEPA, 42 USC 4321 et seq.) requirements for public disclosure and full consideration of feasible alternatives.

Carlquist (1990) traces the socio-political development of the management program, including the two environmental assessments, public meetings, levels of media coverage, and so forth. He also describes compromises perceived necessary by managers to reconcile conflicts between National Park Service management objectives and concerns of various interest groups (particularly sport hunters, animal welfare groups, and a native plant society). Some of these conflicts are described below, but we confine this summary primarily to biological and management considerations.

Experimental Management Program

Objectives of the experimental management program (EMP) were to

1. determine the relative feasibility and cost of various goat removal techniques,
2. conduct studies of goat density and distribution,
3. reduce goat densities in the Klahhane Ridge subpopulation in order to document the species' ability to withstand exploitation,
4. monitor effects of these reduced densities on vegetation and soils, and
5. evaluate sterilization as a means of population control.

Major findings, by objective, were

1. National Park Service biologists, resource managers, and associated personnel captured approximately 693 mountain goats from 1977 to 1989[19] as part of the park's research and management operations, thereby gaining considerable experience with capture and removal techniques. About 233 goats were captured by foot snare (208 by V. Stevens and M. Hutchins), 182 were captured in drop nets, 171 were taken by chemical immobilization (including 135 helicopter captures), and 81 were captured by aerial net-gunning (including 69 removed under contract in 1985). Eighteen goats were shot as biological specimens.

   Each goat removal technique (Table 36) tested had particular strengths and weaknesses. For example, a drop net used effectively to capture goats on Klahhane Ridge required animals that were habituated to accepting bait. Attempts to bait goats at eight other sites in the park during 1982 and 1983 were generally unsuccessful. Darting from helicopters (using the immobilizing drugs M99 etorphine and carfentanil) and net-gunning from aircraft were deemed the capture methods of choice for the subsequent OMP. Shooting from helicopters was among the least expensive and the safest for the field teams. The costs presented in Table 36 represent start-up expenditures only; cost per animal captured rose steeply as goat densities were reduced and survivors became more dispersed and evasive. For example, the cost of drop-net capture on KR was around $400/goat during the initial 1981 removals. By 1984, when the population had been reduced by about 60%, costs were nearly $700/goat.

2–4. Studies of the distribution and density of goats, the response of the KR goats to exploitation, and the effects of goats on vegetation have been detailed previously.

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[19] This tally includes mountain goats captured during a research program initiated 3 years before the EMP as well as those handled during the OMP.

Table 36. Comparison of mountain goat (*Oreamnos americanus*) capture and shooting techniques, 1981–1989, Olympic National Park.[a]

Method	Recapture requirements	Population requirements	Selectivity	Multiple capture	Safety of personnel	Safety of goats	Relative efficiency[b]	Cost per animal[c]
Passive techniques								
Rope snare	Minimal	All densities	Good	No	Good	Good	Poor	Moderate
Other traps/snares	Minimal	High density	Poor	No	Good	Fair	Poor	Moderate
Drop net	Extensive	High density	Good	Yes	Good	Good	Fair	Moderate–high
Active techniques								
Net gun								
Ground	Minimal	All densities	Excellent	No	Fair	Poor	Poor	Moderate–high
Aerial	Minimal	All densities	Excellent	Yes	Poor	Poor	Good	Very high
Chemical immobilization								
Ground	Minimal	All densities	Excellent	No	Good	Fair	Poor	Moderate–high
Aerial	Minimal	All densities	Excellent	No	Fair	Fair	Good	Very high
Drive net	Extensive	Medium-high density	Poor	Yes	Fair	Poor	Poor	Very high
Combined tactics								
Aerial chemical immobilization w/net gun	Minimal	All densities	Excellent	No	Fair	Fair	Poor	Very high
Other								
Manual (heli-jumping following pursuit)	Minimal	All densities	Excellent	No	Poor	Poor	Poor	Very high
Lethal tactics								
Shooting[d]								
Ground	Minimal	All densities	Excellent	N/A	Good	N/A	Fair–good	Very low
Aerial	Minimal	All densities	Excellent	N/A	Good	N/A	Very good	Very low

[a] Capture techniques described in detail in Appendix C. Modified by R. W. Olson in 1993 from National Park Service 1987.

[b] Number of expected captures per unit effort.

[c] Includes transportation from capture site to a front country staging area, but excludes other expenses of goat management programs such as ground transportation to release sites, vegetation monitoring, etc. Low cost = <\$100; moderate = \$101–500; high = \$501-\$1,000; very high = ≥\$1,000.

[d] Data based on biological collections on Klahhane Ridge, Mount Dana, Mount Appleton, Mount Carrie; simulated aerial shooting trials on Mount Dana; euthanasia during capture attempts; and review of other ungulate removal programs.

5. Field sterilizations were attempted on 19 goats (13 females, 6 males; Hoffman 1987; Hoffman and Wright 1990). Males were rendered permanently sterile by chemical vasectomy. Implants of a pregnancy-inhibiting drug (melengestrol acetate [MGA]) apparently rendered females sterile for 3 to 5 years with about 90% effectiveness. Techniques currently available for sterilization, however, were deemed impractical for any large-scale application because of the need to selectively capture and treat each animal and to repeat treatments of females. An ideal sterilization treatment would be permanent, usable on all sex and age classes, and deliverable by dart from helicopter. By the end of the EMP, we had concluded that such a technique did not exist (but see Sterilization below).

Operational Management Program

Objectives for the OMP were to eliminate mountain goats from the 3,250-km^2 core area of the park (Fig. 44) and to control (i.e., reduce) densities along the eastern boundary of the park (about 300 km^2) adjacent to state-managed lands where goats were hunted. Live capture was to be used exclusively for 3 years; shooting would then be used when capture became too expensive, inefficient, or hazardous. The effects of goats on subalpine vegetation were to be monitored throughout the program. An inventory of the abundance and distribution of endemic and rare plants was also to be conducted (see Chapter 12). An advisory committee composed of representatives from agencies and major interest groups was established to monitor the program.

During 1981–89, under provisions of the two environmental assessments, the National Park Service removed 407 goats from the park, including 360 (88%) captured and translocated from the park, 28 (7%) capture-related deaths, and 19 (5%) collected as scientific specimens (Table 37). Two hundred sixty of these animals were removed during 1981–87, under the EMP; 147 were removed during 1988–89, under the OMP. In addition, three known illegal kills occurred in the park, and 111 goats were harvested legally by recreational hunters (archers) outside the park during 1981–89 (Washington Department of Wildlife 1982–90).

Removals during the abbreviated OMP warrant further comment. Based on availability of personnel and funds, park managers set removal goals of 80 goats for 1988 and 120 for 1989. Deaths caused by capture were to be held at 5%. Eighty goats were removed during 1988, with 8.7% capture-related deaths. Only 67 goats were removed during 1989 with 19% deaths (Table 37; Fig. 45). Capture operations were plagued by poor flying weather both years; efforts were canceled 19 of 30 days (67%) between 20 May and 19 July 1988, and 14 of 27 days (52%) between 21 June and 26 July 1989. (Operations usually were not scheduled during weekends and holidays to reduce conflicts with park visitors.)

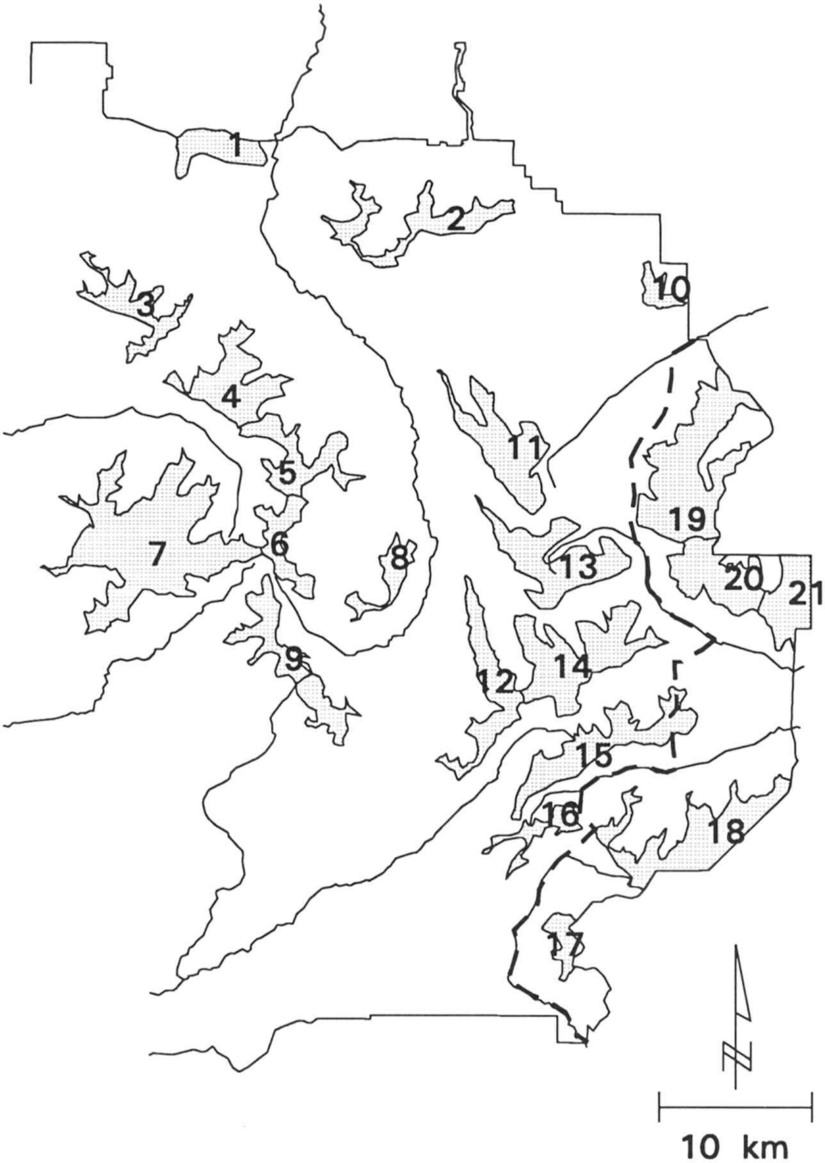

Fig. 44. Spatial distribution of 21 subpopulations of mountain goats in Olympic National Park: (*1*) Hughes Creek, (*2*) Klahhane, (*3*) Appleton, (*4*) Carrie, (*5*) Ferry, (*6*) Barnes, (*7*) Olympus, (*8*) Dana, (*9*) Divide, (*10*) Blue Mountain, (*11*) McCartney, (*12*) Chimney, (*13*) Claywood, (*14*) Anderson, (*15*) LaCrosse, (*16*) Steel, (*17*) Sawtooths, (*18*) Stone, (*19*) Royal, (*20*) Mystery, and (*21*) Constance. *Heavy dashed line* separates the core removal area (west) from the peripheral control area (east). Modified from Hoffman (1987).

Table 37. Mountain goat (*Oreamnos americanus*) removals by location in Olympic National Park, 1981–1989.

Location	1981	1982	1983	1984	1985	1987	1988	1989	**Total**
Mount Anderson					4		2	3	9
Mount Appleton			1	1			9		11
Mount Barnes					2		2	2	6
Blue Mountain							1		1
Mount Carrie						3	4	11	18
Mount Constance							7	5	12
Chimney Peak					3			9	12
Mount Claywood					6		3	2	11
Mount Dana			4		25		7	7	43
Mount Ferry						10		1	11
Hughes Creek							1		1
Klahhane	59	51	52	19	4		17	3	205
Mount LaCrosse								1	1
McCartney Peak								1	1
Mount Mystery								2	2
Mount Olympus							17	10	27
Royal Basin				1			10	3	14
Sawtooth								7	7
Unknown					15				15
Total	59	51	57	21	69	3	80	67	407

Number of goats captured per day of operations averaged 5.0 ± 2.37 SD during 1988 and 6.7 ± 2.06 during 1989. Goat captures per hour of flight time were 1.3 ± 0.38 and 1.3 ± 0.28 during the respective years. These measures of catch per effort did not differ between years (Mann–Whitney *U*-tests, two-tailed, $\alpha = 0.05$).[20] In 1989, capture attempts were sometimes launched in more difficult terrain than during 1988, and mortality increased (mostly from falls sustained during drug induction or netting; R. W. Olson, personal observation). The capture team viewed the increased mortality in 1989 as real, although the proportion of animals dying during capture did not statistically differ between years (χ^2 test, $\alpha = 0.05$). In any event, the goal of 5% capture-related goat mortality was, in retrospect, unreasonable given the circumstances of capture.

As described in Chapter 4, the 1990 estimate of goat numbers in the metapopulation (389 ± 106) was significantly lower than the 1983 estimate (1,175 ± 171).

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[20] Differences were reported erroneously as significant in Houston et al. (1991).

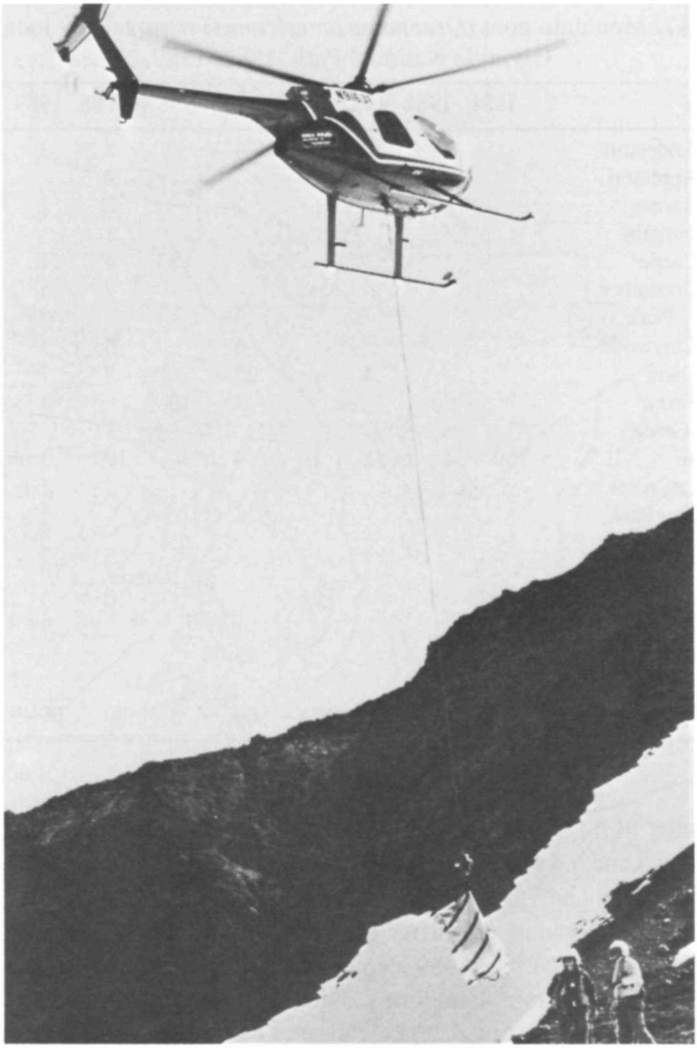


Fig. 45. Two mountain goats, captured by aerial darting, are removed from Olympic National Park, 1988. (Photo by R. W. Olson)

The smaller 1990 population resulted from removals by the National Park Service, perhaps combined with relatively more severe winters (i.e., from exceptionally mild to periodic "average" snowpacks).

The capture operation scheduled for 1990 was canceled by the superintendent of Olympic National Park when two independent assessments indicated that continued efforts posed unacceptable risks to the capture team (Machlis et al. 1990; Peterson 1990). Moreover, a full environmental impact statement, rather than a less comprehensive environmental assessment, was judged necessary to continue with the removal program primarily because of the expected controversy surrounding the option of shooting (M. Finnerty, Superintendent, Olympic National Park, personal communication, 1990).

Future Management

Strategic Options

The National Park Service is preparing an environmental impact statement on goat management in the Olympic Mountains jointly with the U.S. Forest Service (Olympic National Forest) and the Washington Department of Wildlife. Negotiations are difficult because agency management objectives and mandates differ greatly. In addition, the process is being tracked by at least three disparate interest groups, including recreational hunters who wish to retain goats outside the park for sport hunting, a native plant society that wishes to see all goats removed, and an animal welfare group that wishes to see no goats killed. Predicting the outcome of this potentially volatile process demands a prescience that we lack, but a discussion of the management options available to the park in the near term is appropriate.

A recent, perceptive analysis of attempts to control or eradicate feral goats on oceanic islands and habitat islands in New Zealand is relevant to mountain goat management on the Olympic Peninsula (Parkes 1990a, 1990b). From Parkes' perspective, "One of four strategic [management] options may be adopted: no action—giving a stable but undesirable outcome [adverse effects on indigenous biota]; eradication—giving a stable and desirable outcome; annual sustained control—giving a stable and desirable outcome but only if inherently fickle government effort is sustained; and occasional sustained control—giving unstable outcomes with or without the desired results depending on the goals and hunting frequency" (Parkes 1990a:335).

Moreover, to achieve eradication, "Four conditions must be met: all animals must be at risk; there must be no colonisation; the harvesting rate must exceed the rate of increase of the population; and those attempting the task must believe it possible" (Parkes 1990b:297). Four conclusions reached following his analysis of the New Zealand situation seem particularly germane: "Policies of eradication are counterproductive unless they are possible; short intensive campaigns are best; managers should measure and record costs, efforts, and kills to improve planning; [and] cynics are useful if only to check claims of success" (Parkes 1990b:297).

Recognizing conflicting interagency objectives, managers on the Olympic Peninsula have only four broad options for management of mountain goats:

1. Do nothing and allow the entire goat population to achieve ecological carrying capacity (K_l). This would accept goats as part of the fauna and also accept

the consequent changes in vegetation, which could include increased risk of extinction for populations of rare plants. Forego hunter harvest on subpopulations outside the park and manage goats for nonconsumptive (viewing) values.
2. Eliminate mountain goats from the entire Olympic Mountain Range. The metapopulation of goats on the peninsula is isolated, and all animals could be put at risk of removal.
3. Eliminate goat subpopulations from the park but maintain those on the Olympic National Forest and continue to extract a sustained yield by hunting. Because all animals are not at risk, the park must be prepared to control immigrants in perpetuity. Once removal of the park subpopulations was initially completed, control of immigrants would seemingly be a relatively small-scale program, if control were sustained diligently and funding were secure.
4. Annual sustained control and harvest in perpetuity; park subpopulations maintained at low density (e.g., perhaps 0.20 goat/km^2 or lower on summer ranges) and subpopulations on the forest maintained at economic carrying capacity (K_c, see below) by maximum sustained yield harvests.

Different combinations or levels of these options are possible (e.g., park accepts goats at K_l with national forest subpopulations at K_c, or park eliminates subpopulations only from areas with highest densities of endemic–rare plants), but the basic management scenarios available are captured by the four alternatives. Acceptance and execution of any particular strategic option are different matters and depend only to a limited degree on the available removal tactics and expense.

A brief digression into the principles of harvesting large mammals is needed before the options can be evaluated. The following material, greatly simplified, is drawn primarily from Caughley (1977) and Macnab (1985). Consider an ungulate population colonizing a new area. Initially, the population grows at the maximum rate possible—the intrinsic rate of increase (r_m)—because resources are unlimited. The equilibrium eventually reached between the herbivores and their food supply represents the maximum sustainable population level—ecological carrying capacity (K_l). The rate of increase of the animal population at K_l is zero, by definition. To extract a sustained yield (SY) harvest, the density of the population must be reduced below K_l and a positive rate of increase generated. In the simplified logistic harvest model, the maximum sustained yield (MSY) would be generated when the population was reduced to half its equilibrium density ($K_l/2$) and harvested at half the intrinsic rate of increase ($r_m/2$). Thus, a population with K_l of 1,000 and r_m of 0.30 would be reduced initially to 500 animals (economic carrying capacity, K_c) and could then be harvested annually to produce MSY of 75 animals (500×0.15). At harvest rates less than r_m, the population would stabilize at a density between K_l and K_c; if greater, the population would decline to extinction.

What does this mean for mountain goat management? The simplified logistic model would likely overestimate MSY harvests from goat populations, and maximum sustained yields might occur at densities nearer K_l (Fowler 1981a, 1981b; Hoffman 1987; Houston and Stevens 1988). Nevertheless, the model has considerable heuristic value, and we use it to explore the management options outlined above. We then consider a more refined model developed specifically for the Olympic mountain goats.

Hoffman (1987) estimated that $K_l = 1{,}400$ goats for all subpopulations in the park; this estimate was derived by considering the 1983 goat census, the extent of goat removals that had occurred to that date, and the areas of potential habitat as yet uncolonized by goats (combined with his considerable field experience in the Olympic Mountains). This seems a reasonable guess, because about 15% of the goat habitat is outside the park, by extrapolation $K_l = 1{,}650$ for the metapopulation. Two growing subpopulations showed initial rates of increase (r_m) around 0.24, but r_m may have been only 0.10 or less for the metapopulation (see Chapter 4). We cannot predict r_m for the established goat population (and it would likely vary by subpopulation; see Chapter 4), but it would probably lie between these extremes. These estimates of K_l and r_m are used to explore the available management options, and we will disregard, temporarily, the low accuracy and precision of the values. Populations growing at $r = 0.24$ would double in size about every 3 years; at $r = 0.10$, doubling time is about 7 years. We also have assumed that the goat population will indeed rebound from current low numbers, which were imposed, to a large degree, by cropping. This is by no means certain; for reasons that were not entirely clear, cropped populations of mountain goats elsewhere have remained at low levels or continued to decline (e.g., Kuck 1977).

Option 1

Allow the entire population to achieve K_l. This is the easiest to carry out but would be inconsistent with the policies of the National Park Service and the other agencies.

Option 2

This alternative specifies elimination of the entire goat population. At $r_m = 0.24$, a theoretical MSY harvest of 99 goats could be extracted annually from the metapopulation if numbers were reduced to K_c of 825; with $r_m = 0.10$, MSY would be only 41 goats. These removals would have to be exceeded in order to drive the population to extinction. Presumably, however, this option would not start with the metapopulation at K_l. Therefore, the effort theoretically required to eliminate initial populations of 1,000 or 500 goats at the two extreme rates of increase is explored when half the animals present are removed annually (Table 38).

The offtakes from these paper populations could be achieved by either increasing effective mortality (shooting, live capture), reducing fecundity (sterilizations), or some combination. In practice, it would be impossible to halve the population

Table 38. Approximate offtake, years of effort, and cost required to eliminate populations of 1,000 and 500 mountain goats (*Oreamnos americanus*) based on logistic growth models.[a]

			Cost scaling of offtake[b]										Cost scaling of offtake			
Year	*N*	(O)	C	Annual cost	1.1	Annual cost	1.5	Annual cost	2.0	Annual cost	*N*	(O)	S_c	$S_{1.1}$	$S_{1.5}$	$S_{2.0}$
					r_m = 0.24									r_m = 0.10		
1	1,000	(500)	0.1	50.0	0.10	50.0	0.10	50.0	0.1	50.0	1,000	(500)	50.0	50.0	50.0	50.0
2	584	(292)	0.1	29.2	0.11	32.1	0.15	43.8	0.2	58.4	535	(267)	26.7	29.4	40.1	53.4
3	350	(175)	0.1	17.5	0.12	21.0	0.23	40.3	0.4	70.0	290	(145)	14.5	17.4	33.4	58.0
4	212	(106)	0.1	10.6	0.13	13.8	0.34	36.0	0.8	84.8	158	(79)	7.9	10.3	26.9	63.2
5	130	(65)	0.1	6.5	0.15	9.8	0.51	33.2	1.6	104.0	86	(43)	4.3	6.5	21.9	68.8
6	80	(40)	0.1	4.0	0.16	6.4	0.76	30.4	3.2	128.0	47	(23)	2.3	3.7	17.5	73.6
7	49	(24)	0.1	2.4	0.18	4.3	1.14	27.4	6.4	153.6	26	(13)	1.3	2.3	14.8	83.2
8	31	(15)	0.1	1.5	0.20	3.0	1.71	25.7	12.8	192.0	14	(14)	1.4	2.8	23.9	179.2
9	20	(20)	0.1	2.0	0.21	4.2	2.56	51.2	25.6	512.0	0					
10	0															
Total		(1,237)		123.7		144.6		338.0		1,352.8		(1,084)	108.4	122.4	228.5	629.1
				(618.5)[c]		(723.0)		(1,690.0)		(6,764.0)			(542.0)	(612.0)	(1,142.5)	(3,147.0)
1	500	(250)	0.1	25.0	0.10	25.0	0.10	25.0	0.1	25.0	500	(250)	25.0	25.0	25.0	25.0
2	301	(150)	0.1	15.0	0.11	16.5	0.15	22.5	0.2	30.0	271	(135)	13.5	14.9	20.3	27.0
3	184	(92)	0.1	9.2	0.12	11.0	0.23	21.2	0.4	36.8	148	(74)	7.4	8.9	17.0	29.6
4	113	(56)	0.1	5.6	0.13	7.3	0.34	19.0	0.8	44.8	81	(40)	4.0	5.2	13.6	32.0
5	70	(35)	0.1	3.5	0.15	5.3	0.51	17.9	1.6	56.0	45	(22)	2.2	3.3	11.2	35.2
6	43	(21)	0.1	2.1	0.16	3.4	0.76	16.0	3.2	67.2	25	(12)	1.2	1.9	9.1	38.4
7	27	(13)	0.1	1.3	0.18	2.3	1.14	14.8	6.4	83.2	14	(14)	1.4	2.5	16.0	89.6
8	17	(17)	0.1	1.7	0.20	3.4	1.71	29.1	12.8	217.6	0					
9	0															
Total		(634)		63.4		74.2		165.5		560.6		(547)	54.7	61.7	112.2	276.8
				(317.0)[c]		(371.0)		(827.5)		(2,803.0)			(273.5)	(308.5)	(561.0)	(1,384.0)

[a] N = numbers present in each subsequent year calculated from $N_x\lambda$, where $\lambda = 1 + r$ for "birth pulse" populations (Eberhardt 1987) and where $r = r_m(1 - N/K)$ (Caughley 1977:179) and K = 1,650 goats. Offtake (O) = 50% of the population is removed annually.

[b] Cost is in thousands of dollars. Initial cost is $100/goat removed; cost scaled either to remain constant (C), increase 10%, (factor of 1.1), increase 50% (1.5), or double (2.0) each time the population is halved. S = sum of annual costs. Multiplier columns omitted for r_m = 0.10 examples.

[c] Sum of campaign expenditure using initial removal cost of $500/goat.

annually using sterilization (see below, and indeed, kids represent only about 20% of the population).

In the worst-case scenario—population of 1,000 goats, $r_m = 0.24$, and initial offtake costs of $100/animal doubling each time numbers are halved—elimination requires removal of 1,237 animals over 9 years at a cost of nearly $1.4 million; costs approach $6.8 million using an initial removal expense of $500/animal. At the other extreme—500 goats, $r_m = 0.10$, and costs constant at $100/animal removed—547 goats are removed in 7 years at cost of $55,000; campaign costs are $274,000 at the figure of $500/animal. These extreme scenarios are unrealistic; removal costs will surely not remain constant as the population is reduced, but it is difficult to see them doubling annually in the latter stages of a program if the increased cost is due mainly to additional helicopter search time—even recognizing that removal of the last few animals would be enormously expensive. Cost increases of 10–50% annually over the first half of a campaign to some plateau in the second half seem more likely. (Note that Table 38 may be modified easily to accommodate different starting or ending population sizes, offtake rates, or cost factors. An initial cost of $1,000/animal treated or removed is entirely possible, as shown in Table 36.)

None of the scenarios qualifies as the short intensive campaign recommended by Parkes (1990a, 1990b), which we define arbitrarily here as 5 years. On paper, short campaigns are easy to accomplish: for the population of 1,000 goats ($r_m = 0.24$), if the targeted removals for years 4 and 5 were increased to 150 and 70 goats, respectively (versus 106 and 65), the population would be extinguished in 5 years. Shortening the prolonged effort by 4 years results in enormous monetary savings for the scenarios where removal costs escalate rapidly; for example, where costs double annually, the total expenditures of 5-year programs are only 30% of those for campaigns lasting 9 years.

This exercise illustrates some important points. First, elimination of a large population with high rates of increase would be difficult and costly; the converse also is true. If eradication is the option selected, then initiating the campaign when populations are at low levels, for whatever reason, makes the most biological and financial sense. Second, short intense campaigns where removals greatly exceed increases are indeed best, if for no other reason than cost containment. We appreciate the great disparity in cost among the scenarios, but at this time (April 1994), we do not know when or if a removal program will be launched or what removal tactics will be considered acceptable. We can be sure that none of the models will mimic exactly the response of the metapopulation to control.

As indicated, the logistic model overestimates a mountain goat population's ability to respond to removals. Hoffman (1987) developed a stochastic (i.e., parameters were allowed to vary randomly within prescribed limits) simulation model of population growth for the metapopulation of the Olympic goats that incorporated age specific fecundity and mortality, age distributions, and dispersal rates among 21 subpopulations (Fig. 46). Parameters for the model components were obtained from field surveys (his own and those made earlier, including

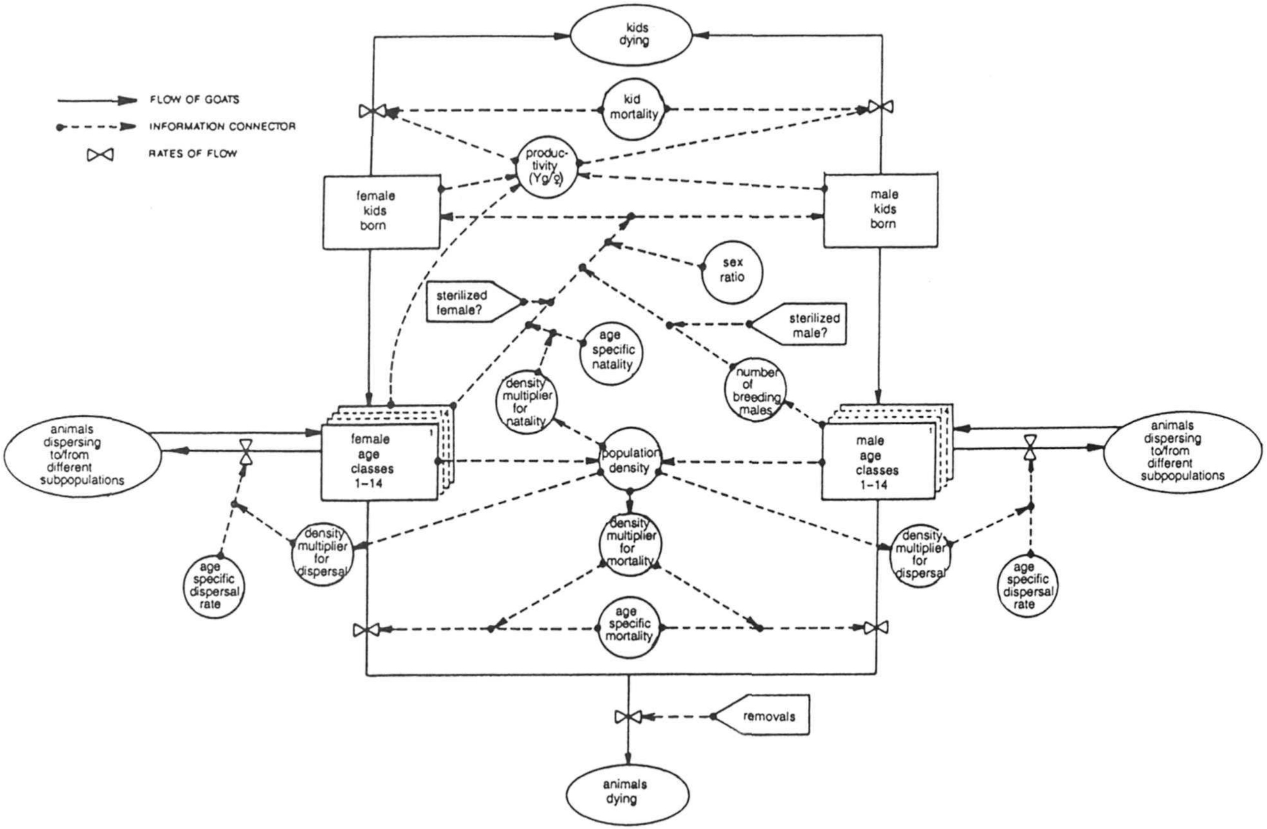


Fig. 46. Structure of a stochastic simulation model of the dynamics of the Olympic mountain goats. From Hoffman (1987).

Chapter 5 and Stevens 1983) and the literature. Each decision in the model (dying, dispersing, etc.) was made using Monte Carlo methods (Hammersley and Handscomb 1965), where possible outcomes were assigned probabilities of being chosen based on the predicted probability of occurrence in the system being modeled. The model then randomly selected one outcome based on these predetermined probability distributions. Simulated outcomes were used to test a variety of management scenarios (e.g., random vs. systematic removals with regard to the spatial distribution of subpopulations, May vs. August removals, and male vs. female sterilizations).

The model provided insight into the reduction alternatives; little difference occurred in time to extinction between random or systematic removals or with the time of year of removals (Hoffman 1987). Removals of 100 animals/year from an initial population of 1,000 goats required an average of 15.2–16.1 years to drive the model population to extinction (depending on the removal scenario; Fig. 47). The model was designed primarily to evaluate the relative effectiveness of live removals and sterilization (as opposed to shooting), so only scenarios involving treatments of up to 100 goats/year (a most ambitious goal) were tested. Direct comparisons with the logistic model are limited, but at a removal rate of 100/year, it also predicted that populations with $r_m = 0.10$ would persist for about 15 years. But at $r_m = 0.24$, goats would persist essentially indefinitely, as nearly 950 would remain following 40 years with these constant removals.

Sterilization scenarios showed that at least 50 animals/year (either males or females) would have to be treated and at least 15 years would be required to drive the population to extinction (Fig. 48). Insufficient information on goat breeding behavior was available to choose the most appropriate scenarios of male and female sterilization. Although we cannot predict with certainty which model (logistic or stochastic) would most closely mimic the actual population's response to removals, both demonstrated that elimination would require formidable effort.

Option 3

Elimination from the park while maintaining sustained yields from the remaining population on the national forest is a variation on option 2 that would leave perhaps 200 goats and seemingly commit the National Park Service to removal of immigrants in perpetuity. Assuming that park subpopulations could be removed to initiate this option, at the effort and cost described above, keeping the park goat-free over the long term might be more difficult (and expensive) than first anticipated. This pessimism results from the difficulty of tracking immigration. Even though the number of annual immigrants would be small (perhaps up to 20 individuals if, at a worst case, 10% of the remaining subpopulations immigrated; Stevens 1983), goats could disperse across a large area and would be difficult to detect. If half the park summer range (about 21,000 ha) was searched annually for immigrants at the intensity of the goat census (0.04 min/ha), then 14 h of helicopter search time would be required plus perhaps an additional 6 h for such items as ferry time and

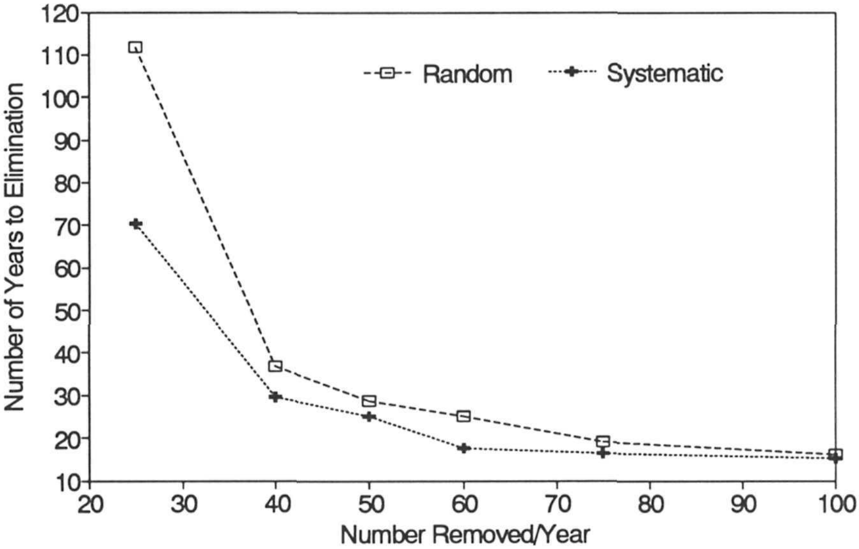


Fig. 47. Comparison of random versus systematic removals with time-to-elimination of the mountain goat population using the May removal scenario of the population model; initial population of 1,000 goats. *Lines* represent means of 40 model runs of each scenario (25, 40, 50, 75, and 100 removals/year). From Hoffman (1987).

refueling trips. At $550/h, the annual cost would be $11,000. Additional costs (personnel, equipment, etc.) could increase this estimate to perhaps $20,000/year. Several years of low returns might convince financially hard-pressed administrators that funds would be better spent elsewhere—possibly setting the stage for recolonization.

However, the goats remaining outside the park would not occur as a single cohesive subpopulation but would be fragmented into small numbers along the eastern edge (primarily) of the park. The ability of such small groups to persist long-term is unknown but may be doubtful (e.g., Berger 1990) even without hunting. (The potential K_I might be raised for subpopulations that reside outside the park by deliberately enhancing winter habitats with prescribed burning [e.g., Johnson 1983:55], thus easing the risk of extinction.)

Option 4

Maintain park populations at low density (0.20 goat/km^2 or around 100 animals) and national forest populations at K_C (perhaps 150–200 goats) for a metapopulation of 250–300. This option suffers from the difficulties of option 3 (questionable viability of remaining low-density subpopulations and fickle agency commitment of scarce funds in perpetuity), plus the added problem of low precision in determining goat numbers (i.e., wide confidence intervals surrounding estimates—to

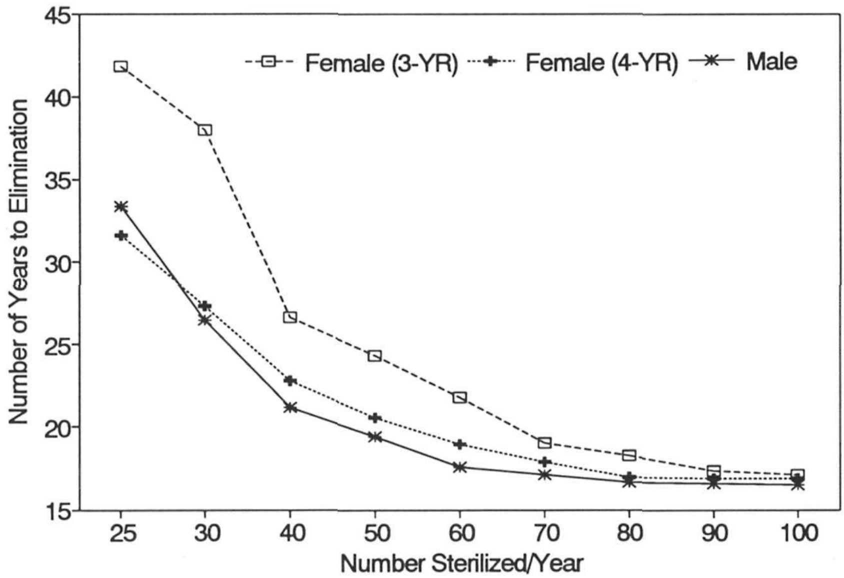


Fig. 48. Comparison of the most conservative male sterilization model with female sterilization on number of years to elimination using the stochastic population model; female sterilization effective for 3 and 4 years and using an initial population of 1,000 animals. *Lines* represent means of 40 model runs of each scenario (25, 40, 50, 75, and 100 removals/year). From Hoffman (1987).

be expected based on all earlier counts). Low precision means that tracking actual subpopulation numbers closely enough to maintain MSY harvests on the national forest and the narrowly defined limits of acceptable densities in the park would be nearly impossible. We suspect that, for reasons of cost and the likelihood of shifting budget priorities over time, this program could easily shift from the proposed annual sustained control to occasional sustained control (Parkes' option 4) by default.

Tactics

Only three broad tactics are available to control or eliminate the goat population: live capture, field shooting, and sterilization (other lethal possibilities such as use of toxicants are considered to be unacceptable, as are habitat manipulation schemes such as fencing goats out of selected endemic plant populations). Effectiveness and costs of any management program hinge on which tactics or combination of tactics are selected. After 8 years of effort, park personnel have good understanding of the usefulness and limits of various techniques in the formidable Olympic Mountains.

Live Capture

Of the 10 capture techniques tested (Table 36), only net-gunning and darting from helicopters were feasible for the removal of relatively large numbers of goats over extensive areas. Although several subpopulations were essentially eliminated using live capture (including Klahhane Ridge where a drop net was used initially and where the two goats remaining in 1990 were males), the limits of the techniques, in terms of human safety, were judged to have been reached by 1989. Accessible animals and subpopulations had been removed, but at least 300 goats remained in the park. The remaining goats occurred in small groups or in several large subpopulations that occupied exceedingly precipitous terrain that was considered essentially unworkable for live capture (Fig. 49). Hence, the metapopulation cannot be eliminated using aerial live capture. Conversely, if the population is allowed to rebound, animals will reoccupy terrain from which they could be live-captured but still with appreciable risk to the capture teams.

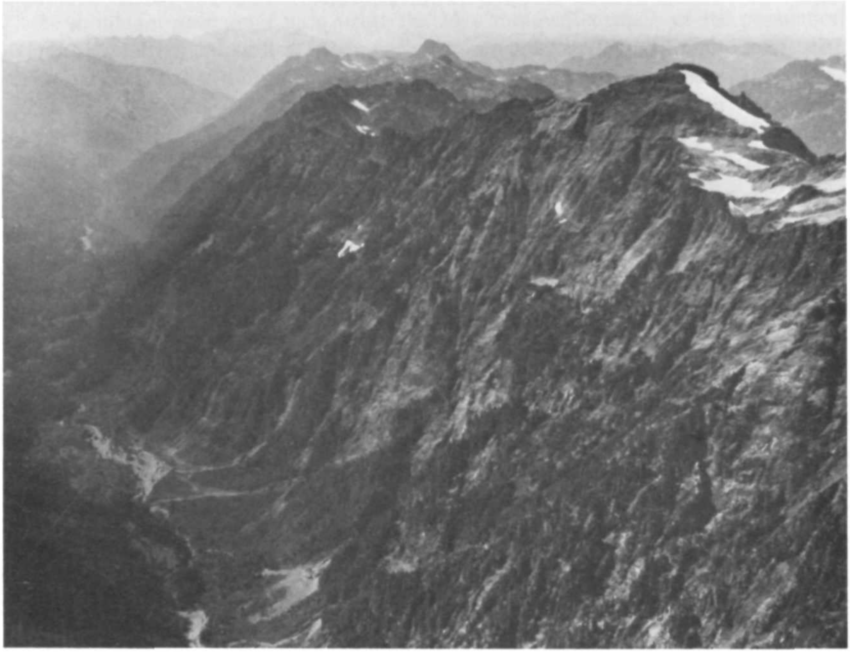


Fig. 49. Chimney Peak with the Quinault River at left. Goats occupying the precipitous, south-facing escarpment (extending about 1,400 m from the valley floor) were essentially unworkable using capture techniques.

Shooting

Our experience with aerial shooting is limited to collecting eight biological specimens and to one simulated shooting sortie conducted to estimate costs in 1983 (Olson 1984, 1992). Aerial shooting is among the least expensive removal options tested (Table 36). Because capture techniques alone exceeded rates of increase and dramatically reduced several subpopulations, the combination of ground and aerial shooting, with the possibility of working essentially all terrain, seemingly could greatly reduce or eliminate many other subpopulations. Whether or not the metapopulation could be driven to extinction by shooting is unknown because removal of the last few animals would be difficult and expensive. Shooting from the ground has been used elsewhere to eliminate feral goats (Parkes 1990a, 1990b), and aerial shooting for commercial harvest apparently devastated populations of thar, a mountain ungulate introduced to New Zealand (Caughley 1983).

Sterilization

A panel of five scientists recently conducted an independent, on-site review to evaluate the potential for contraceptives or sterilants to control or eliminate mountain goats in the park (Warren et al. 1992). The panel reviewed current technology and the previous experimental sterilization efforts (e.g., Hoffman 1987) as well as the overall goat management program. They concluded

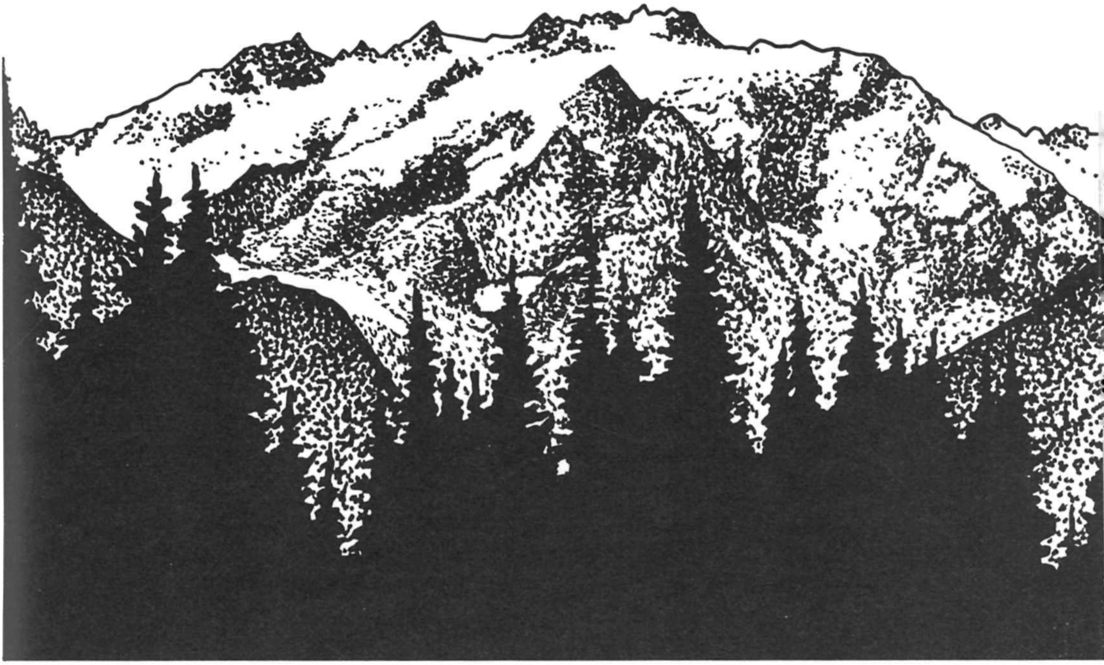
> ... that there currently are no remotely deliverable contraceptives or sterilants available that have been proven to provide long-term infertility or permanent sterility in mountain goats. Even if such contraceptives or sterilant agents were available, the panel believes treating mountain goats in the park with these agents would represent a very expensive, never-ending program that, at best, would only partially control the population. Therefore, despite the fact that each member of the panel is personally committed to developing non-lethal control techniques for wildlife, they came to the unanimous conclusion that lethal shooting appears to be the only feasible option for use in eliminating mountain goats from Olympic National Park. Indeed, even with the use of lethal shooting, it likely will be very expensive and difficult to totally eliminate goats from the park (Warren et al. 1992:1).

The panel estimated that a sterilization or contraception program could cost as much as $1–2 million—10 times more than a shooting program (by their estimate)—and would still not eliminate the population. They concluded that "at best, currently available contraceptives or sterilants could be used to (1) maintain a population at a stable level, (2) reduce the rate of population increase, or (3) slowly reduce population numbers over a long period of time (i.e., the life expectancy of a mountain goat; possibly as long as 10–15 years)."

Finally, “It is likely that research developments within the next 10–20 years may provide a ‘one-shot’ permanent sterilant that may be applicable for mountain goat management at ONP [Olympic National Park]. However, even if such a sterilant is developed in the future, it will likely never eliminate mountain goats from ONP.”

The bottom line of this overview of management strategies and tactics shows that all control or elimination options will be difficult and expensive to achieve in practice. As difficult and costly as elimination of the metapopulation could be (option 2), sustained control (options 3 and 4) will be more so, especially if reduction in fecundity (sterilization) is the tactic applied. Any management program selected will surely test the stamina and commitment of agency managers.

Acknowledgments



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Appendixes

Appendix A1: Vegetation Sampling

E. G. Schreiner

Subalpine and Alpine Plant Communities

Plant communities were sampled with plots similar to those described by Franklin et al. (1971a) and Henderson et al. (1989) for forest vegetation. We used relatively small, variable-sized plots (20–100 m^2) because extensive areas of homogeneous vegetation were uncommon at high elevations in the Olympic Mountains. The generally rectangular or square plots were located in vegetation that typified plant communities in the vicinity. Evidence of herbivore activity was not used as a criterion for locating individual plots, and plots were never placed near sites where salt had attracted mountain goats (*Oreamnos americanus*; see below).

Variables recorded included plant cover by species, substrate characteristics, slope, aspect, and elevation. Cover was estimated in classes of trace and percentages of <1, 1–5, 6–25, 26–50, 51–75, 76–95, and 96–100. Small cover classes at each end of the scale prevented overestimates of species with low cover and underestimates of species with extremely high cover. The same classes were used to estimate cover of mosses, lichens, litter, organic matter, bare soil (<2-mm particles), total rock, bedrock, and five size classes of loose rocks (diameters of >2 mm–4 cm, 5–10 cm, 11–20 cm, 21–70 cm, and >70 cm).

Plant communities were classified using Two-Way Indicator Species Analysis (TWINSPAN). This method groups plots with similar cover and species composition (Hill 1979; Gauch 1982). Our data set included plant community survey plots (*n* = 705), permanent plots from Klahhane Ridge (*n* = 6) and Mount Constance (*n* = 6), and plot data from Belsky (1979; *n* = 11) and Pfitsch et al. (1983; *n* = 43). We sampled plots in 22 areas that represented regions of high and low precipitation as well as high (>3 goats/km^2), medium (1–3 goats/km^2), and low goat density (<1 goat/km^2). Plots were concentrated in the eastern half of the park because most goat summer range occurred there (Houston et al. 1986).

Salt was used during 1972–84 on Klahhane Ridge to bait mountain goats into a single site where a dropnet was used to capture them (Johnson and Moorhead 1982). Goats were strongly attracted to salt for several weeks annually (approximately mid-June to early July), evidently for the sodium content (Hebert and Cowan 1971; Stevens 1979). During 1981–84, salt was maintained in a large rubberized tub to minimize the amount that escaped into the soil. Salt and tub were removed at the end of the trapping period. Some salt did escape into the soil (e.g., by spills or overflow during rains), and goats clearly devastated vegetation and soil within a 50-m radius of the site. We do not believe, however, that such intensified effects extended beyond the site. In particular, the salt did not increase goat densities in the Klahhane Ridge subpopulation either seasonally or year-round. Studies of 130 tagged goats on Klahhane Ridge showed that most were residents on the 3,900-ha area; they did not come from afar to consume salt. Klahhane Ridge provided excellent goat habitat, and goats certainly did not face rigors of that particular environment year-round merely to lick salt for a few weeks in summer. We believe that the location of the salt site had no effect on the overall goat densities on Klahhane Ridge or on studies of relations between goats and vegetation (i.e., the nearest vegetation plot was about 0.75 km distant from the salt site).

Baiting goats with salt also was attempted at eight other sites in the park (including Mount Dana) during the summers of 1982 and 1983. Baiting proved unsuccessful, so the salt was removed.

Interactions Among Herbivores, Plants, and Soils

Evidence of animal use was recorded in the plots used to classify plant communities in mountain goat summer range (Appendix A2). Animal sign in each plot was quantified by species to the extent possible. Scat piles, tracks, wallow or bedding sites, and marmot dens in each plot were counted. In addition, the number of wallow or bedding sites and marmot dens within 50 m of each plot and the number of trails crossing each plot were tallied. Animals in or near plots were noted.

A combination of factors was considered in determining which species of ungulate produced the sign. Roosevelt elk sign was identified by track and pellet size since both are considerably larger than those of mountain goats or black-tailed deer. Tracks were identified as having been produced by goats or deer based on shape. Deer tracks taper and are narrower toward the front while goat tracks have little taper, tending to be square or rectangular. Wallow or bedding sites and pellet groups were assigned to mountain goats or deer by the presence of other sign including identifiable tracks and the presence of hair (mainly goats). Mountain goat hair was a particularly useful indicator because goats annually shed winter coats in June and July, which left hair on rocks and plants in areas frequented by goats—hair did not persist through the subsequent winter (Schreiner, personal observation). Pellet groups, tracks, and wallows were classified as unidentified ungulate when the species responsible was uncertain. Deer and unidentified ungulate sign were combined during analysis because most unidentified sign was probably deer (i.e., we used a conservative approach with respect to identification of goat sign).

A grazing index (GI) for each species was obtained by estimating the proportion of plants with evidence of substantial grazing in each plot in classes of trace and percentages of 1–5, 6–25, 26–50, 51–75, and 76–100. An individual was considered to be substantially grazed only if ≥25% of the foliage or stems had been cropped. In practice this meant that 25% of the culms in graminoids, 25% of the leaves in forbs, and 25% of the branches in shrubs had to be grazed before the proportion was estimated. Trace was entered when all plants (of a given species) in a plot had <25% of their foliage or stems cropped or if only flower stalks were cropped. It was not our intent to estimate the amount of standing crop removed by herbivores. Instead, we sought to create an index of grazing that could be compared among plots, areas, and plant communities. Armstrong and MacDonald (1992) noted that proportional estimates such as this are useful when comparing grazing levels among areas but that estimates of utilization (i.e., standing crop or biomass removed by herbivores) require intensive field studies.

Two indicators were used to characterize grazing on a plot basis. Average grazing provided an estimate of how intensely a plot had been grazed:

$$\text{average grazing} = \frac{\text{sum of the grazing values (GI) for each species}}{\text{number of species}}$$

Percent of species grazed (PSG) was calculated by comparing the number of species with evidence of substantial grazing to the total number of species in a plot (i.e., species richness). High values of PSG indicated that herbivores grazed most of the species present in a plot and low values indicated that herbivores were more selective, grazing few of the available species. The index was calculated using only those species where more than 5% of the individuals of that species had been cropped at least 25% (i.e., GI >5%). Therefore, incidentally grazed species were not included. The formula was

$$\text{percent of species grazed (PSG)} = \frac{\text{number of species with GI} > 5\%}{\text{number of species}} \times 100$$

An index of herbivore selection of particular plant species was calculated by comparing plant frequency to grazing frequency as follows:

$$\text{species relative grazing frequency (SRGF)} = \frac{\text{grazing frequency}}{\text{plant frequency}} \times 100$$

Pfitsch and Bliss (1985) describe a similar index, also called species relative grazing frequency (SRGF), based on 1- × 1-m quadrats. They classified species as preferred (SRGF ≥50) and avoided (SRGF ≤25). However, because their index did not consider availability, it did actually estimate relative preference or avoidance in the conventional sense (Crawley 1983). To allow comparisons with their work, we used similar criteria but classified species as selected (SRGF ≥50) or nonselected (SRGF ≤25).

Each study area was classified according to the estimated density of mountain goats (see Fig. 32). Categories were high, medium, and low density based on estimates from 1986 except for two areas where we had additional information. The 1986 estimates reflected the 1983 mountain goat census (Houston et al. 1986), observations during live capture operations during 1984–85, and field observations by park staff (National Park Service 1987). Mount Angeles (1982) and Deer Park (1988) plots were assigned goat density levels based on more detailed information. We believe that there was good concurrence between the 1986 goat density estimates and goat density at the time of measurement because most plots ($n = \sim 600$) were established during 1983–86. Natural mortality and goat removals from 1988 to 1989 may have reduced correspondence between estimated and actual density for plots established during 1988–90. However, most of the 1988–90 plots were in areas already classified as low goat density. Goat density estimates used in the analyses were prepared independently of the process used to select study areas. Our initial selection of study sites included areas of high and low goat density based on the work of Stevens (1979, 1983) and perceptions of the field crew.

Responses of Vegetation to Reductions in Goat Density

Permanently marked plots were established in areas of homogeneous vegetation representative of plant communities in three areas. Plots were 100 m^2 unless a smaller 25–40-m^2 plot had to be used because the area of homogeneous vegetation was small (i.e., Avalanche Canyon where plant cover was sparse). Vegetation characteristics in each plot were estimated on 6–12 1- × 1-m quadrats selected using a stratified–random design.

Cover was estimated using plot frames gridded with string so that each square represented 1% of the quadrat.[1] The gridded frame helped minimize variability between estimates obtained by different investigators and provided for accurate estimates to the nearest 1%. Training sessions were conducted each year to ensure that crew members estimated plant cover similarly. Cover classes were trace = <0.1%, <1 = 0.1–0.5%, 1 = 0.5–1.0%, 2 = 1.1–2.0%, and so on to 100%. Grazing

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[1] We selected cover as a measure of plant abundance over time because reliable estimates can be made rapidly by experienced observers. Thus we optimized time and accuracy. Most other measures of plant abundance (e.g., frequency, density, standing crop, basal area) suffer from one or more shortcomings. For example, basal area and density are suitable parameters for plants with individual stems (or clumps) but are difficult to apply to rhizomatous plants or forbs with poorly defined "basal area." An advantage of cover is that estimates can be applied to all growth forms (Mueller-Dombois and Ellenberg 1974). We employed quadrat frames to estimate cover because we judged the pin drop method as too time consuming (i.e., we needed to sample a greater area than this method would have allowed). See Daubenmire (1968) and Mueller-Dombois and Ellenberg (1974) for additional discussion.

(i.e., GI) was estimated using grazing classes of trace and percentages of 1–5, 6–25, 26–50, 51–75, and 76–100.

Klahhane Ridge

Klahhane Ridge is located in the north end of Olympic National Park, about 12 km south of the Strait of Juan de Fuca. Pfitsch and Bliss (1985) identified nine plant community types ranging from windswept ridges dominated by cushion plants to late snow areas dominated by *Carex nigricans*. Two communities, *Phlox–Festuca* and *Phacelia* scree (unstable herb meadow), account for most of the unforested vegetation in the area. Both communities become snow-free by late May or early June and compose 94% of available meadow vegetation in early summer and 59% in late summer.

Five permanent plots were established on Klahhane Ridge and one at Deer Park (as a control) in 1983 and were studied until 1990. Plots were established initially in areas of high, moderate, and low goat use by previous observations of goat behavior. Moderate- and low-use plots were combined for analyses. Cover values represented the maximum of mid-July, early-August, and late-August samplings by species.[2]

Herbivores observed utilizing Klahhane Ridge included mountain goats, marmots, and black-tailed deer. Goats were observed mainly from 1983 to 1986, and black-tailed deer and marmots were seen from 1983 to 1990. Deer seemed to increase utilization of the Klahhane Ridge area as goat density was reduced.

Mount Dana

Mount Dana is located in a high precipitation region, 17 km east of Mount Olympus. Plant communities represented a subset of those found throughout goat summer range. The TWINSPAN classification of plots (n = 189) revealed eight plant community types. Dry site communities found elsewhere in the park (e.g., *Astragalus*–scree) were not encountered at Mount Dana. Additionally, some communities found in other areas (*Carex–Valeriana*, *Delphinium*–scree, *Senecio*–scree) were not well represented. Typical communities included *Phyllodoce empetriformis*, *Carex spectabilis–Lupinus latifolius*, and *Phlox diffusa–Carex phaeocephala*.

One permanent plot in each of five community types was established in 1984. Cover was estimated in late July or early August 1984–86, 1990, and 1992. Results were predisposed to greater phenological variability because sites could be sampled only once per season. Plots at Mount Dana were divided into high and low initial goat use classes by using the number of species grazed (NSG) more than 5% (i.e., GI >5%) in each 10- × 10-m plot as an indirect measure of the intensity of goat use. The number of species grazed in high use plots at Klahhane Ridge was initially greater than that in low use plots and declined as goat density was reduced. The value of NSG in the high use plots ultimately was equal to or less than that in low use plots. Consequently, we used NSG as an estimate of goat use levels at Mount Dana (and Avalanche Canyon).

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[2] We used maximum cover values measured each year for among-year comparisons. Comparisons based on similar dates (e.g., 24 August) were inappropriate because measurements were influenced strongly by temporal variation in growing season (i.e., extent of drought, time of snowmelt, etc.; Schreiner 1987). We believe maximum cover values approximated peak annual standing crops.

Herbivores utilizing the Mount Dana area included elk, mountain goats, deer, marmots, and bear (actually an omnivore). Relatively limited observations during the study period (i.e., ~1 week/year in late July or early August, 1983, 1984, 1990, 1992) indicated that mountain goats utilized snow patches, meadows, and rocky outcrops along the east and north flanks of Mount Dana and open areas just south and west of the summit. On hot summer days, mountain goats utilized east-facing rock outcrops and debris chutes as low as 800 m. Extensive *Carex spectabilis* meadows below and southwest of the summit were used mainly by elk, bear, and marmots. Deer, their beds, and their tracks were most commonly observed in subalpine fir forests and among subalpine fir clumps above the *Carex spectabilis* meadows and below the summit of Mount Dana. Thus there was overlap in the sites used by goats and marmots but little overlap between sites used by goats and those used by elk, deer, and bear.

Avalanche Canyon

Avalanche Canyon is located near the eastern border of Olympic National Park just west of Mount Constance. The region is incredibly rugged and is known for its scree slopes, loose rock, and numerous prominent peaks (Olympic Mountain Rescue 1988)—vegetation is sparse. Plants occurred mainly on scree, talus, rock outcrops, and a few relatively stable benches. Species associated on talus slopes with delayed snowmelt (e.g., *Elmera racemosa*) were more common in Avalanche Canyon than at Klahhane or Dana. Individual plots were dominated by *Luetkea pectinata*, *Phyllodoce empetriformis*, *Carex spectabilis*, *Phlox diffusa*, *Phacelia hastata*, or *Delphinium glareosum*. Meadows characteristic of goat summer range elsewhere in the park were essentially absent.

Six permanent plots were established during 1988. Four plots were located in relatively unstable scree slopes dominated by *Phacelia hastata* or *Delphinium glareosum* and two on relatively stable sites dominated by *Phlox diffusa*. Cover was measured once in 1988 and in late July and late August 1989–92. The maximum cover value for each species in each year was used for analysis.

Attempts to classify plots as high or low initial goat use were unsuccessful because NSG values fluctuated considerably. Therefore, we used a crude approximation of goat use derived from the grazing index. Plots were divided into two groups: decreasing use where grazing occurred only during 1988–89 ($n = 2$) and stable or increasing use where grazing remained constant, increased, or occurred only during 1990–92 ($n = 4$).

Herbivore use in Avalanche Canyon was mainly by mountain goats. Elk and bear or their sign were not observed; marmots occurred occasionally, and deer were seen infrequently. Observations of goats, hair, and grazing in permanent plots and the surrounding area indicated they were the major herbivore present and that overall goat use remained more or less constant during the study.

Photographic Comparisons: A Qualitative Appraisal of the Influence of Climate and Disturbances on Vegetation, 1915–1990

Sources searched for photographs included the Clallam County Historical Society, park files, and records of two O'Neil expeditions (1885 and 1890), early mountaineers, pioneers, rangers, and others known to travel the mountains (e.g., E. B. Webster, the Cameron family, Doc Ludden). Many photographs were located during a historic resources study (Evans 1983).

We analyzed general features of photographic pairs (see Plates 1–11 in Chapter 11), then described and tallied differences (if any) in each community. The following categories were used:

1. Total plant cover;
2. Percent cover of disturbance-oriented species (*Achillea millefolium*, *Cirsium edule*, *Phacelia hastata*);
3. Cover of plants indicating community stability (*Festuca idahoensis*);
4. Cover of shrubs (mainly *Juniperus communis*);
5. Number and height of trees;
6. Cover of bare ground and rock;
7. Number of trails and wallow or bedding sites;
8. Obvious changes in cover of fine soils and pebbles <2 cm in diameter; fines were either exposed or replaced by gravel or cobble-size rocks; and
9. Soil erosion or deposition as indicated by increased or decreased exposure of roots and large rocks.

Most scenes contained more than one plant community, so comparisons of several communities were often possible from a single pair. The foreground, for example, might show a ridgetop community while the background showed a north-facing slope of *Abies lasiocarpa*. Additionally, if two different photographic pairs contained views of the same site from a different angle, only one community view was included in the analysis.

Temperature and precipitation data were obtained from the Port Angeles weather station, 12 km north of the study area (National Oceanic and Atmospheric Administration 1910–91). Snow depth data are for April from the Hurricane Ridge snow course, 3 km southwest of Mount Angeles (Soil Conservation Service 1960, Olympic National Park records). April records were used because they were closest to the growing season and therefore gave a crude indication of soil moisture available to plants the following summer. Climatic trends were plotted using a technique called Locally Weighted Regression Scatter Plot Smoothing (LOWESS; Chambers et al. 1983).

Rare Plants—*Astragalus*

Habitat sampling was conducted in the Blue Mountain and Mount Angeles areas where most *Astragalus* occurred. All subpopulations, with the exception of one containing approximately 200 plants north of Blue Mountain, were sampled—nearly one-third of all *Astragalus* plants were included. Plots were located in areas of physical site homogeneity that included at least one *Astragalus* individual and were distributed over the complete range of environmental conditions observed in each subpopulation. Plant cover, grazing, animal use, and environmental parameters were recorded using the same methods described previously for plant communities and herbivore–plant community interactions. Additionally, the number of *Astragalus* seedlings and mature plants in each plot were counted.

In 1985, 10 of the 25-m^2 plots were marked permanently to measure *Astragalus* population trends. Plot sides were marked temporarily with short steel nails at 1-m intervals, and cotton string was used to grid the entire 5- × 5-m plot into 25 1- × 1-m squares. *Astragalus* individuals in each square meter were mapped and counted and grazing or other physical injuries to each plant noted. Seedlings also were counted and mapped in 1987, 1988, 1990, and 1991.

Appendix A2. Subalpine and Alpine Plant Communities

E. G. Schreiner

During 1981–90, we sampled subalpine and alpine vegetation to describe and classify plant communities (Appendix A1). Our study represented vegetation on mountain goat summer range, except that we did not sample the Mount Olympus massif (mostly rock, snow, and ice) or the central Bailey Range. Sixteen plant communities were identified at elevations above 1,520 m (see text Fig. 9; Table A1).

Scree and Talus Communities

Scree and talus slopes are often encountered in the Olympic Mountains because of the steep, rocky terrain and predominance of soft, sedimentary bedrock. Four plant communities were associated with scree and talus. One occurred on steep, bare slopes near ridges; the others were found mainly on colluvial debris fans below massive rock outcrops (i.e., mountains). Distinguishing features of the scree and talus communities were high proportions of rock fragments in the >2-mm–4-cm and 5–10-cm classes; steep (30–35°) slopes; unstable substrates; and 57–97% mineral soil and rock cover (Table A2). Aspect and elevation further distinguished these four communities.

The driest of the four scree and talus communities was dominated by the endemic *Astragalus australis* var. *olympicus*. Present only in the driest region of the park, this community occurred on soils with pH 6.0 or higher (Kaye 1989). Total plant cover was 7%.

The three colluvial fan communities were differentiated by aspect, elevation, and substrate. Slopes dominated by *Phacelia hastata* occurred on dry south exposures averaging 1,737 m elevation; those dominated by the endemic *Senecio neowebsteri* occurred on slightly higher (1,814 m) and cooler northwest to northeast exposures (Table A2). Sites dominated by *Delphinium glareosum* were found on south- to northwest-facing exposures at an average elevation of 1,860 m. Most rocks at the surface in the *Senecio* and *Delphinium* communities were in the >2-mm–4-cm and 5–10-cm size classes; a higher proportion of the substrate was bare mineral soil in sites where *Phacelia* dominated. Total plant cover was 9% in *Senecio*, 25% in *Delphinium*, and 55% in *Phacelia* communities.

Table A1. Mean cover (C) and percent frequency (F) of dominant species in subalpine and alpine communities.

	Scree and talus communities								*Phlox diffusa* communities											
																	Pachistima			
Species code	*Astragalus*		*Phacelia*		*Delphinium*		*Senecio*		*Potentilla*		*Festuca*		*Carex*		*Juniperus*		*Sedum*		*Phacelia*	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
Ast Aus	2.5	90																		
Cre Nan	0.3	45																		
Cam Pip	0.2	31																		
Phl Dif	0.5	55	1.4	48			0.1	40	3.9	98	14.1	90	8.5	100	3.6	91	7.2	90	5.8	100
Ach Mil	0.3	35	1.2	50	0.3	33			1.6	83	2.7	88			0.7	75	0.5	46	0.6	54
Pot Fru									4.4	64					1.2	32				
Eri Com	0.1	33							0.7	77					0.2	34				
Pha Ser	0.2	43			0.2	33			0.6	64										
Sit Hys	0.1	31							0.3	60					0.2	45				
Sme Cal									0.8	43										
Sol Mul									1.7	42										
Syn Pin									1.1	36										
Fes Ovi									0.4	60			0.2	40	0.3	59				
Luz Spi									0.4	42										
Fes Ida									1.0	47	11.0	85								
Ago spp.			0.4	66							1.3	69								
Sil Par											1.0	66					1.1	43	0.4	46
Are Cap											3.6	62	0.4	31						
Cam Rot											1.2	44								
Vio Adu											0.5	45			0.2	32				
Pol Bis											1.1	41								
Ali Cre											1.2	35								
Car Pha									1.2	55	0.5	31	3.8	79	0.2	48				
Tri Spi											1.0			57	0.3	45				
Car Spe													2.2	31						
Lup Lat			2.9	26									3.5	40	1.9	43				

Table A1. *Continued.*

Species code	Scree and talus communities								*Phlox diffusa* communities											
																	Pachistima			
	Astragalus		*Phacelia*		*Delphinium*		*Senecio*		*Potentilla*		*Festuca*		*Carex*		*Juniperus*		*Sedum*		*Phacelia*	
	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F	C	F
Jun Com															15.4	84				
Sax Bro															1.1	64				
Pen Dav															1.4	66	0.9	51	0.1	19
Epi Ang															0.3	32				
Sed Div							0.2	47							0.5	50	1.2	71	2.6	73
Pac Myr																	3.4	60	1.7	58
Dou Lae					0.2	33			0.7	38			0.5	40	0.6	59	1.6	66		
Cry Cri																	0.3	54	0.2	27
Lui Hyp																	1.4	34	1.4	31
Pha Has			10.5	89	2.0	33											0.3	30	1.7	100
Epi Alp			1.1	74	1.4	61	0.7	80					0.1	36						
Hyd Fen			6.9	57																
Cir Edu			3.4	53																
Ast Pau			3.6	48													1.1	43	0.1	27
Art Lud			6.1	50															2.5	54
Bro Sit			0.4	48																
Del Gla					11.1	100	0.3	40												
Col Deb					0.6	39														
Sen Neo					1.6	33	1.8	93												
Elm Rac							0.7	53												
Oxy Dig							0.1	33												
Total cover	7.0		54.7		25.7		8.7		32.9		67.3		31.3		39.4		34.8		32.0	

Table A1. *Continued.*

Species code	*Carex spectabilis* communities										Late snowmelt community	
	Valeriana		*Vaccinium*		*Lupinus*		*Phyllodoce*		*Cassiope*		*Luetkea–Saxifraga*	
	C	F	C	F	C	F	C	F	C	F	C	F
Car Spe	16.2	86	10.5	78	14.2	88	2.9	65	1.5	76	0.7	33
Val Sit	2.5	77	1.8	59								
Pte Aqu	2.0	2			1.0	11						
Epi Alp	0.8	77									0.1	33
Ver Vir	3.7	42										
Ast Pau	2.2	44										
Cir Edu	0.9	40										
Bro Sit	0.5	30										
Vac Del	4.5	23	25.7	75	1.0	15	13.7	63	1.1	22		
Lup Lat	4.2	51	13.1	88	8.7	63	2.2	42				
Pol Bis	1.5	70	3.7	94	2.1	63	1.5	65	0.6	35		
Eri Per	1.0	42	2.1	75	1.8	45	0.2	31				
Hie Gra			0.5	69	0.9	67	0.8	77	0.9	81	0.1	33
Luz Cam			0.5	63	0.4	50	0.3	49	0.2	41		
Poa Sec	0.5	35	0.3	44					0.2	32		
Lue Pec			3.6	41	6.1	61	5.6	78	12.2	86	4.6	78
Jun Par					2.5	52	1.6	34	2.4	49		
Lom Mar					0.4	46						
Phl Dif			0.6	38	4.0	57			0.4	41		
Phy Emp			2.6	41			26.9	89	1.1	43		
Ery Mon							0.6	32				
Cas Par							0.4	48	0.5	38		
Cas Mer							6.0	31	12.7	70	0.4	33
Abi Las									4.9	57	0.1	33
Luz Par	0.4	37	0.4	38					0.7	51	1.1	44
Ant Lan					1.3	28			5.4	43		
Rho Alb									1.1	5		

Table A1. *Continued.*

Species code	*Carex spectabilis* communities										Late snowmelt community	
	Valeriana		*Vaccinium*		*Lupinus*		*Phyllodoce*		*Cassiope*		*Luetkea–Saxifraga*	
	C	F	C	F	C	F	C	F	C	F	C	F
Sax Tol											3.2	78
Des Atr											1.9	67
Jun Dru											1.1	78
Sax Fer											0.4	44
Car Nig					1.3	16					9.0	33
Jun Mer											0.4	33
Ran Ver											0.1	33
Total cover	61.7		105.5		61.9		74.9		55.0		26.5	

Table A2. Mean environmental and substrate characteristics by community type. Substrate data represent mean percent cover.

Community type	Slope (°)	Aspect	Elevation (m)	Total rock	Bare soil	Bedrock	Rock size class (cm)				Litter	Organic matter
							1–4	5–10	11–20	>20		
Scree and talus communities												
Astragalus	30	SW	1,698	90.1	9.3	6.9	62.3	12.2	5.2	3.5	0.6	0.1
Phacelia	35	SE–SW	1,734	55.2	16.7	1.6	24.6	15.9	8.6	4.5	3.7	0.9
Delphinium	32	SE–SW	1,868	78.6	13.8	0.4	42.3	20.2	10.0	5.7	0.3	0.1
Senecio	33	NE–NW	1,813	81.3	10.9	0.2	39.6	25.0	10.8	5.7	0.4	0.3
Phlox diffusa communities												
Potentilla	22	All	1,839	77.2	7.5	4.6	34.0	20.3	12.6	5.7	3.3	0.5
Festuca	26	SE–SW	1,698	42.4	13.3	2.1	23.7	11.5	3.4	1.7	8.4	0.8
Carex phaeocephala	30	S–SW	1,843	67.1	3.0	15.9	14.0	15.3	13.7	8.2	1.6	0.4
Juniperus	34	E–W	1,813	59.9	4.5	20.8	8.7	11.7	7.1	11.6	5.6	3.3
Pachistima–Sedum	41	SE–SW	1,717	70.1	11.5	31.0	16.6	8.2	6.3	8.6	2.2	0.6
Pachistima–Phacelia	36	SE–SW	1,677	60.9	23.7	17.6	19.7	10.8	5.2	7.6	1.8	0.3
Carex spectabilis communities												
Valeriana	35	All	1,617	32.3	5.6	0.3	12.2	7.8	7.4	4.6	11.7	7.7
Vaccinium	37	SE–NW	1,678	18.5	5.3	2.0	5.8	4.5	3.3	3.0	15.0	6.3
Lupinus	31	E–SE	1,796	45.9	4.8	8.6	18.7	8.9	4.7	5.1	7.7	3.1
Phyllodoce	30	NE–SE	1,731	28.2	4.1	8.9	6.3	5.2	4.1	3.8	19.2	6.8
Cassiope	31	NW–NE	1,830	57.6	7.0	17.6	15.3	9.4	6.7	8.6	5.3	0.8
Late snowmelt community												
Luetkea–Saxifraga	29	W–NW	1,633	72.6	8.6	9.0	21.4	11.1	12.9	18.1	1.5	3.2

Phlox diffusa Communities

Six plant communities contained *Phlox diffusa* as a dominant or codominant. These are differentiated on the basis of slope and substrate characteristics. Slope ranged from 22° in the *Phlox–Potentilla* community to 41° in the *Phlox–Pachistima* type (Table A2). Two communities with relatively low slope, (*Phlox–Potentilla*, *Phlox–Festuca*), had only a small percentage of exposed bedrock at the surface (<5%); the other four were usually located on steeper slopes with 16–31% exposed bedrock. *Phlox diffusa* was dominant in five communities and codominated with *Juniperus communis* in the sixth.

The distribution and aerial extent of the *Phlox* communities reflected the influence of climate, substrate characteristics, and glacial history. The *Phlox–Festuca* community, for example, was limited to a narrow band from Hurricane Ridge southeast to Constance Pass. Sites supporting this grassy meadow type were dry but relatively stable with an average slope of 26° (Table A2). Exposed bedrock was low (2%) and plant cover was high (65%). The *Phlox–Potentilla* community occurred at higher elevations than the *Phlox–Festuca* type (1,864 m) often just below ridgecrests; these sites, characteristically blown free of snow in winter, were alpine rather than subalpine.

Four of the *Phlox* communities occurred mostly on exposed bedrock. Plants typically occurred within cracks and in depressions where soil had accumulated. Slope stability was higher than that of scree communities because exposed bedrock seemed to inhibit soil and rock movement—slope varied from 30 to 41°. Community types included *Phlox–Carex phaeocephala*, *Juniperus–Phlox*, and two phases of a *Phlox–Pachistima* type (one with *Phacelia hastata*). The *Phlox–Carex phaeocephala* type occurred only on Mount Dana and could have represented an early successional community or a steeper, wet-site version of the *Phlox–Potentilla* community. This community was unusual because wetter-site species, *Carex spectabilis* and *Lupinus latifolius*, codominated with the dry-site species, *Phlox diffusa* and *Carex phaeocephala*.

Carex spectabilis Communities

Environmental differences were not distinct among some of the plant communities at the wetter end of the classification scheme. *Carex spectabilis* dominated or was an important constituent of all communities in this group. The *Carex–Valeriana* and *Vaccinium deliciosum* types were found on steep slopes (35–37°) from 1,615 to 1,675 m elevation with little bedrock at the surface (Table A2). The *Carex–Lupinus* type was widespread and occurred primarily on east to southeast-facing exposures averaging 1,800 m in elevation. The heath-dominated communities were dominated by *Phyllodoce empetriformis* on southerly exposures at elevations averaging 1,730 m and by *Cassiope mertensiana* on higher (1,830 m), northerly exposures.

There were differences among substrate characteristics of the five *Carex spectabilis* communities. Exposed bedrock averaged 17% in *Cassiope* communities compared to about 8.5% in *Phyllodoce* and *Carex–Lupinus* communities, and 2% or less in the *Vaccinium* and *Carex–Valeriana* types. Total rock cover was lowest in the *Vaccinium* and *Phyllodoce* communities.

Most plots classified in the *Carex spectabilis* or *Phyllodoce* community types were located in wetter areas of the park, west of the Elwha River and south of the Dosewallips River. One community, *Vaccinium*, was not observed or sampled in the dry Mount Angeles–Deer Park area. The *Carex–Lupinus* community was sampled in all areas of the park—it was more common on north-facing exposures in the Mount Angeles area as opposed to south-facing exposures in regions receiving greater precipitation. Some communities, such as the *Phyllodoce empetriformis* type, were more common in moderately sloped cirques and basins not sampled in this study (e.g., Seven Lakes Basin). These areas were not typical of summer range for goats (Stevens 1979).

Luetkea–Saxifraga Community

The *Luetkea–Saxifraga* type was sampled infrequently. It occurred on west to northwest-facing exposures—a fairly high proportion of the substrate was composed of larger rocks (11–70 cm). Plant cover was low (26%). This community occurred on sites that seemed to have been recently colonized by plants.

Interpretation

A comparison of communities described in this study with those delineated by Kuramoto and Bliss (1970) and Pfitsch and Bliss (1985) showed concurrence, but we identified additional community types. Differences among the studies arose because Kuramoto and Bliss (1970) concentrated on subalpine meadows; Pfitsch and Bliss (1985) examined communities in a comparatively small area; and the number of plots sampled in our study was greater (700+) than the ~40 sampled by Kuramoto and Bliss (1970) and the ~30 sampled by Pfitsch and Bliss (1985). Additionally, plant community patterns in goat summer range were often fine-grained (i.e., community types often changed over distances of ≤5 m) because of interactions among substrate, time of snowmelt, slope stability, and precipitation.

Availability of soil moisture seemed to be the primary environmental factor controlling plant community composition and distribution. Average annual precipitation, date of snowmelt, aspect, and elevation combined to produce local moisture regimes. Previous investigators of Olympic Mountain subalpine and alpine communities reached similar conclusions (i.e., Fonda and Bliss 1969; Kuramoto and Bliss 1970; Canaday and Fonda 1974; Belsky and del Moral 1982; del Moral 1983b; Pfitsch and Bliss 1985; Smith and Henderson 1986).

Slope and substrate characteristics (i.e., particle size and the quantity of bedrock near the surface) played secondary but crucial roles in controlling plant community composition. The exact nature of interactions between substrate and available moisture remains unclear, but it seemed that sites with later snowmelt and bedrock near the surface developed heath communities while drier sites favored the *Phlox–Pachistima* community. Field observations suggested that parent material (i.e., sedimentary, slate, or basalt) also influenced plant community composition, although Kuramoto and Bliss (1970) reported similar chemistry among soils developed on different parent materials. Soil stability also affects subalpine and alpine vegetation patterns (Bliss 1969; Bell and Bliss 1973; Hansen 1976; Belsky and del Moral 1982; del Moral 1984; Pfitsch and Bliss 1985)—stability may be influenced by parent material and substrate size.

Plant community composition and distribution in the Olympic Mountains may reflect past glacial events. Kuramoto and Bliss (1970), for example, suggested that the *Phlox–Festuca* community could be a remnant of communities that were more widespread during maximum Holocene warmth (10,000–4,000 B.P.). The distributions of several plant species and communities suggest the existence of glacial refugia in the north and northeastern Olympic Mountains (see Chapter 3).

Subalpine and alpine plant communities are exposed to harsh environmental conditions. High winds, cold temperatures, snow, short growing seasons, freeze–thaw cycles, nutrient-poor soils, and soil moisture conditions play a role in community and species development (Bliss 1971). Microenvironmental factors such as soil temperature, wind, and soil moisture strongly influence plant growth and reproduction in these zones (e.g., Bliss 1956, 1971; Johnson and Billings 1962; Holway and Ward 1965; Billings 1974). These environmental constraints also influence subalpine and alpine meadow vegetation of the Olympic Mountains (Bliss 1969; Kuramoto and Bliss 1970; Canaday and Fonda 1974; Loneragan and del Moral 1984).

Appendix A3. Selected and Nonselected Plant Species

E. G. Schreiner

Table. Selected and nonselected plant species at Klahhane Ridge and Mount Dana and species grazed initially (by mountain goats [*Oreamnos americanus*]) and grazed later at Avalanche Canyon. Species listed for Klahhane Ridge are from Pfitsch and Bliss (1985).

Selected	Nonselected
Klahhane Ridge	
Agoseris spp.	*Antennaria* spp.
Artemisia ludoviciana	*Arabis* spp.
Aster paucicapitatus	*Arenaria rubella*
Bromus sitchensis	*Cassiope mertensiana*
Campanula rotundifolia	*Cirsium edule*
Carex spectabilis	*Delphinium glareosum*
Erigeron peregrinus	*Deschampsia atropurpurea*
Festuca idahoensis	*Erysimum arenicola*
Hedysarum occidentale	*Hieracium gracile*
Lomatium martindalei	*Juniperus communis*
Lomatium nudicaule	*Lathyrus nevadensis*
Poa secunda	*Luetkea pectinata*
Polygonum bistortoides	*Orthocarpus imbricatus*
Silene parryi	*Polygonum douglasii*
	Ranunculus eschscholtzii
	Vicia americana
Mount Dana	
Agoseris spp.	*Abies lasiocarpa*
Carex rossii	*Antennaria lanata*
Carex spectabilis	*Antennaria microphylla*
Deschampsia atropurpurea	*Arenaria capillaris*
Hieracium gracile	*Cheilanthes gracile*
Juncus parryi	*Claytonia lanceolata*
Pachistima myrsinites	*Cryptogramma crispa*
Polygonum bistortoides	*Douglasia laevigata*
Silene parryi	*Epilobium alpinum*
	Festuca ovina
	Juniperus communis
	Luetkea pectinata
	Lupinus latifolius
	Phlox diffusa
	Sedum divergens

Appendix A3. *Continued.*

Grazed initially	Grazed later
Avalanche Canyon[a]	
P1 *Achillea millefolium*	*Agoseris* spp.
Arabis spp.	*Arnica* spp.
Hieracium gracile	*Carex nigricans*
Juncus parryi	*Carex phaeocephala*
Lomatium nudicaule	*Carex spectabilis*
Luzula spicata	*Carex* spp.
Pachistima myrsinites	*Lomatium martindalei*
Poa cusickii	*Penstemon procerus*
Poa secunda	*Polygonum bistortoides*
Poa spp.	*Silene parryi*
Senecio flettii	*Veronica cusickii*
Solanum multiradiata	
P2 *Bromus sitchensis*	*Agoseris* spp.
Cirsium edule	*Castilleja miniata*
Hydrophyllum fendleri	*Polemonium pulcherrimum*
Lomatium martindalei	
P3 *Cirsium edule*	*Achillea millefolium*
Hydrophyllum fendleri	*Agoseris* spp.
Lomatium martindalei	*Elmera racemosa*
	Epilobium alpinum
P4 *Aquilegia formosa*	*Agoseris aurantiaca*
Arabis spp.	*Agoseris* spp.
Arnica latifolia	*Campanula rotundifolia*
Arnica spp.	*Carex nigricans*
Hydrophyllum fendleri	*Carex spectabilis*
Juncus spp.	*Carex* spp.
Phleum alpinum	*Cirsium edule*
Viola adunca	*Epilobium alpinum*
	Erigeron peregrinus
	Lomatium martindalei
	Penstemon procerus
	Poa cusickii
	Poa spp.
	Polygonum bistortoides
	Sibbaldia procumbens
	Silene parryi
	Trisetum spicatum
	Veronica cusickii
P5 *Arabis hirsuta*	*Bromus sitchensis*
Delphinium glareosum	*Campanula rotundifolia*
Poa secunda	*Epilobium alpinum*
Sedum divergens	*Epilobium* spp.
Viola adunca	*Hydrophyllum fendleri*
	Poa spp.
	Sitanion hystrix

Appendix A3. *Continued.*

	Grazed initially	Grazed later
P6	*Phacelia hastata* *Phleum alpinum*	*Delphinium glareosum* *Epilobium alpinum* *Luzula parviflora* *Poa* spp. *Senecio flettii* *Valeriana sitchensis*

[a] P1 to P6 = Sample plot numbers.

Appendix A4. Plant Codes and Scientific Names

E. G. Schreiner

Code	Genus	Species	Variety or ssp.
Abi Las	*Abies*	*lasicocarpa*	
Ach Mil	*Achillea*	*millefolium*	
Ago spp.	*Agoseris*	spp.	
Ali Cre	*Allium*	*crenulatum*	
Ant Lan	*Antennaria*	*lanata*	
Are Cap	*Arenaria*	*capillaris*	
Art Lud	*Artemisia*	*ludoviciana*	
Ast Aus	*Astragalus*	*australis*	*olympicus*
Ast Pau	*Aster*	*paucicapitatus*	
Bro Sit	*Bromus*	*sitchensis*	
Cam Pip	*Campanula*	*piperi*	
Cam Rot	*Campanula*	*rotundifolia*	
Car Nig	*Carex*	*nigricans*	
Car Pha	*Carex*	*phaeocephala*	
Car Spe	*Carex*	*spectabilis*	
Cas Mer	*Cassiope*	*mertensiana*	
Cas Par	*Castilleja*	*parviflora*	
Cir Edu	*Cirsium*	*edule*	
Col Deb	*Collomia*	*debilis*	*larsenii*
Cre Nan	*Crepis*	*nana*	*nana*
Cry Cri	*Cryptogamma*	*crispa*	*acrostichoides*
Del Gla	*Delphinium*	*glareosum*	
Des Atr	*Deschampsia*	*atropurpurea*	
Dou Lae	*Douglasia*	*laevigata*	
Elm Rac	*Elmera*	*racemosa*	
Epi Alp	*Epilobium*	*alpinum*	
Epi Ang	*Epilobium*	*angustifolium*	
Eri Com	*Erigeron*	*compositus*	
Eri Per	*Erigeron*	*peregrinus*	
Ery Mon	*Erythronium*	*montanum*	
Fes Ida	*Festuca*	*idahoensis*	
Fes Ovi	*Festuca*	*ovina*	
Hie Gra	*Hieracium*	*gracile*	
Hyd Fen	*Hydrophyllum*	*fendleri*	*albifrons*
Jun Com	*Juniperus*	*communis*	*montana*
Jun Dru	*Juncus*	*drummondi*	*subtriflorus*
Jun Mer	*Juncus*	*mertensianus*	
Jun Par	*Juncus*	*parryi*	

Appendix 4. Continued.

Code	Genus	Species	Variety or ssp.
Lom Mar	*Lomatium*	*martindalei*	*flavum*
Lue Pec	*Luetkea*	*pectinata*	
Lui Hyp	*Luina*	*hypoleuca*	
Lup Lat	*Lupinus*	*latifolius*	
Luz Cam	*Luzula*	*campestris*	
Luz Par	*Luzula*	*parviflora*	
Luz Spi	*Luzula*	*spicata*	
Oxy Dig	*Oxyria*	*digyna*	
Pac Myr	*Pachistima*	*myrsinites*	
Pen Dav	*Penstemon*	*davidsonii*	
Pha Has	*Phacelia*	*hastata*	
Pha Ser	*Phacelia*	*sericea*	
Phl Dif	*Phlox*	*diffusa*	*longistyla*
Phy Emp	*Phyllodoce*	*empetriformis*	
Poa Sec	*Poa*	*secunda*	
Pol Bis	*Polygonum*	*bistortoides*	
Pot Fru	*Potentilla*	*fruticosa*	
Pte Aqu	*Pteridium*	*aquilinum*	
Ran Ver	*Ranunculus*	*verecundus*	
Rho Alb	*Rhododendron*	*albiflorum*	
Sax Bro	*Saxifraga*	*bronchialis*	
Sax Fer	*Saxifraga*	*ferruginea*	*macounii*(?)
Sax Tol	*Saxifraga*	*tolmiei*	
Sed Div	*Sedum*	*divergens*	
Sen Neo	*Senecio*	*neowebsteri*	
Sil Par	*Silene*	*parryi*	
Sit Hys	*Sitanion*	*hystrix*	*hystrix*
Sme Cal	*Smelowskia*	*calycina*	*americana*
Sol Mul	*Solidago*	*multiradiata*	*scopulorum*
Syn Pin	*Synthyris*	*pinnatifida*	*lanuginosa*
Tri Spi	*Trisetum*	*spicatum*	
Vac Del	*Vaccinium*	*deliciosum*	
Val Sit	*Valeriana*	*sitchensis*	
Ver Vir	*Veratrum*	*viride*	
Vio Adu	*Viola*	*adunca*	?

Appendix B. Review of the Historical Evidence Relating to Mountain Goats in the Olympic Mountains Before 1925

S. Schultz

The generally accepted perception that mountain goats (*Oreamnos americanus*) were not part of the historic fauna of the Olympic Mountains has recently been challenged (Lyman 1988; Anunsen 1993). These challenges have been based in part on a conjectured reconstruction of mountain goat distribution in the Pacific Northwest during the late Quaternary and the speculation that goats in remote areas of the Olympic Mountains may have gone unreported during early surveys. The latter notion is reinforced by historical accounts of widespread use of mountain goat wool among the native people living along the Strait of Juan de Fuca and a few early passing references to the presence of goats in the Olympic Range.

These concerns led the National Park Service to reexamine information concerning the past occurrence of mountain goats on the Olympic Peninsula. Schalk (1993) evaluated ethnographic and archeological evidence relative to the prehistoric occurrence of goats. My review examines early accounts of explorations on the Olympic Peninsula, paying special attention to wildlife observations and statements concerning the presence or absence of mountain goats before their 1925 introduction. Historic references to native use of mountain goat wool on the Olympic Peninsula and in the surrounding area also are considered. A variety of sources was consulted, including published and unpublished expedition narratives, journals, field notes, and correspondence; early newspaper accounts; U.S. Geological and Biological Survey published reports and unpublished field records; catalogues of mammals; territorial governors' reports; U.S. Forest Service files; and selected nineteenth- and early twentieth-century literature on natural history, recreation, and game hunting. Manuscript collections at the Smithsonian Institution, the Library of Congress, the Bancroft Library of the University of California at Berkeley, and other reference libraries were searched for relevant material. A complete bibliography containing references searched but not cited here is contained in a draft of this report (Schultz 1993).

The review of information about the possible historic occurrence of mountain goats in the Olympic Mountains involves the problem of interpreting negative evidence (Lyman 1988). If mountain goats were indeed not present, no reported sightings of them should be expected. However, a failure to find reported evidence of mountain goats in the historic record cannot alone be used to argue that mountain goats were not present: a failure to report is not proof of absence. In fact, there are a few historic accounts that assert that mountain goats were present in the Olympics. Therefore, as many pre-1925 accounts of wildlife observations as could be located, whether or not they mentioned goats, were examined. The following pages review these accounts and attempt to evaluate their completeness, the author's opportunity for firsthand observation or his reliance on credible informants, and the likelihood that mountain goats would have been reported if they had been observed. Sufficient narrative and interpretive detail are provided to clarify the context (and limits) of each account. The discussion attempts to assess the reliability of the various reports. The overall effort has been to provide a thorough, careful, and balanced consideration of all located records that pertain to the issue.

Maritime Explorers

Spanish Coastal Exploration, 1790–1792

The discovery of the Strait of Juan de Fuca, the waterway between the southern shore of Vancouver Island and the north coast of the Olympic Peninsula, has been attributed to a Greek mariner who sailed for Spain under the name of de Fuca in 1592. Although the western entrance and perhaps other portions of the strait were visited by English, Spanish, and American navigators during the late 1780's, Spanish explorers were the first to chart the entire length of the strait in 1790 (Fig. B1). In that year, Spanish naval lieutenant Francisco Eliza dispatched Manuel Quimper in one ship, *Princesa Real*, from the port of Nootka on the west coast of Vancouver Island to explore the interior of the Strait of Juan de Fuca. During June and July, Quimper charted both the north and south coasts of the strait as far inland as the San Juan Islands. From an anchorage at Dungeness, on the northern coast of the Olympic Peninsula, his party explored the eastern end of the strait, discovering the entrances to Haro and Rosario straits to the north, Port Discovery (later so named by Vancouver) and Protection Island, and the opening of Admiralty Inlet. Quimper noted that the Indians at Dungeness wove woolen cloaks, but he did not describe the wool (Wagner 1933:131). On his return, Quimper visited points along the north coast of the strait, Freshwater Bay on the Olympic Peninsula, and Neah Bay, which he named Núñez Gaona when he took possession of it on 1 August. There he observed "sea otters, bears, deer, rabbits, foxes and dogs" (Wagner 1933:127).

In a general description of the terrain and wildlife found along the Strait of Juan de Fuca, Quimper states

> The mountains on the north side are suggestive of some fertility, and of being traversed along their summits. On their slopes, land which

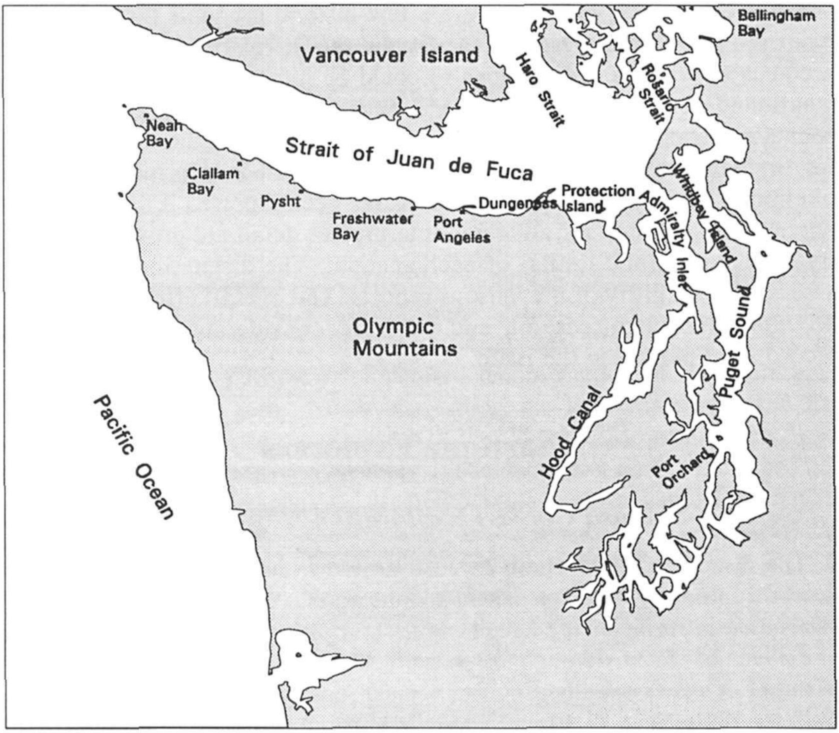

Fig. B1. Spanish anchorages and landings (1790–1792) and areas visited by Vancouver in 1792.

> seems suitable for crops was noted, from which various small streams run down and empty into the strait. Those on the south side are exactly like those on the north side except for their height. As this is very great their summits are covered with snow. I therefore do not think they can be traversed. On some, high pines and other trees can be seen. Buffalo, stags, deer, wild goats, bears, leopards, foxes, hares, and rabbits feed on their luxuriant pastures, and uncommonly large partridges, quail and other unknown kinds of little birds on their seeds (Wagner 1933:128).

Wagner indicates that the word "cibolos," translated as "buffalo," was the term used in the early Spanish reports for elk, an animal with which the Spaniards were unfamiliar (Wagner 1933:162). Wagner does not indicate what term was translated as "wild goats." However, it is highly unlikely that the Spanish explorers could have seen mountain goats from shipboard or from their anchorage near lowlands at Dungeness. They made no explorations of the interior other than to locate water and to hunt for food in areas close to the coast. There is no record of specific observations of wildlife made on specific dates in the available translated narratives. Quimper's statement, therefore, is an unsupported generalization.

The following year Eliza was instructed to carry out further explorations in the Strait of Juan de Fuca. On 26 May 1791, he entered the strait with two ships, the *San Carlos* and the schooner *Santa Saturnina*. After a month spent exploring among the San Juan Islands and in the Strait of Georgia, they crossed the strait to Dungeness on 28 June, and the next day moved to Port Discovery. On 1 July the schooner and a longboat under the command of José María Narváez left Port Discovery to explore the coastline to the east and as far north as the vicinity of Texada Island. Narváez saw a number of whales in the Gulf of Georgia and speculated that it must have another entrance in addition to the Strait of Juan de Fuca, where they had only noted three or four whales. The *San Carlos* remained in Discovery Bay for 25 days.

According to Henry Wagner, historian of these expeditions, "Eliza does not enter into any detailed description of the animals, birds and fish found in the strait because as he said, Quimper had described them the year before" (Wagner 1933:34). However, Eliza did give a detailed description of an elk that was shot at Discovery Bay:

> A great abundance of deer is found in these places, among which are some larger than any horse and having more flesh than any steer. ...The shape of the body, feet and legs is like those of a very large horse. The hoof is like that of a bull, the ear like that of a mule and the horns like those of a deer, except that they are extremely large and thick, each being one yard and two inches long with six points or little horns each ten to thirteen inches long. All the animals are also found which occur in the description of the Estrecho de Fuca by Don Manuel Quimper (Wagner 1933:151).

The pilot of Eliza's ship, Juan Pantoja y Arriaga, provided some additional information on the elk and the use of wool blankets by the Indians of that area. Pantoja does not elaborate whether the blankets were made of goat wool or wool made from the hair of dogs. Both types were in use among Olympic Peninsula tribes (Schalk 1993).

> The horns are entirely covered with a skin of down, not very thick but very close-grained, so fine that when we touched it we seemed to be passing our hands over velvet. What he has on his body however is just the reverse as it is the same as that on a deer. The color of the head is between black and brown and that of the horns between ash color and dark pearl color. When they were dressing it there were some Indians present who explained very clearly that it was of the skin of this animal

> that they made their beautiful and perfectly dressed leather shirts, which ordinarily all possess. We bought some of these which look like the breast doublets in Spain but are very thick. On asking them if they made use of these to protect themselves from intemperate weather they said "no", but that for that purpose they had and wear an abundance of blankets of very coarse wool, with which most of the crew have supplied themselves, and that they only used these skins during their skirmishes or war to protect themselves from the arrows (Wagner 1933:179).

Pantoja also noted that other animals observed at Discovery Bay were "bears, leopards, coyotes, wolves, deer, hares and rabbits and two kinds of doves and chickens" (Wagner 1933:188). Wagner noted the "leopards" were probably cougars. The mention of coyotes is interesting because they are not thought to have taken up residence on the Olympic Peninsula until early in the twentieth century, after the wolf had been practically eliminated and logging had opened up some of the heavily timbered areas. Reagan's report of them (1909a) seems to be the first (Scheffer 1949:58). Pantoja's list of animals found along the Strait of Juan de Fuca is a generalization very similar to the statement made by Quimper.

> On both coasts, particularly on the shores, different kinds of pasture are very common on which feed buffalo, stags, deer, wild goats, hares and rabbits. On the seeds and abundant fruits, some of which are agreeable to the palate, two kinds of doves feed, one of the color and shape of our domestic pigeon, different unknown little birds and a kind of the color and shape of a chicken, with golden feathers and a swift flight like that of the partridge (Wagner 1933:184).

Current common names of mammals and birds Quimper and Pantoja may have observed include cougar, bobcat, wolf, black bear, elk, black-tailed deer, snowshoe hare, ruffed and blue grouse (*Bonasa umbellus*, *Dendragapus obscurus*), band-tailed pigeon (*Columba fasciata*), and mourning dove (*Zenaida macroura*).

Spain launched one final exploring expedition into the Strait of Juan de Fuca in June 1792. Two schooners, *Sutil* and *Mexicana*, commanded by Dionisio Alcala Galiano and Cayetano Valdés, sailed from Nootka and arrived at Neah Bay on 6 June. After leaving Neah Bay on 8 June, the expedition had no further contact with the Olympic Peninsula. However, the account of this expedition is interesting for its observations of the use of wool among various Native American tribes encountered along the coastlines of Vancouver Island and the British Columbia mainland. On the schooners' arrival at Esquimalt Harbor on the southeast end of Vancouver Island, they were met by Indians in canoes.

> When we came near Eliza anchorage, three canoes, with four or five Indians in each, approached the *Mexicana*. ...The natives were dressed in cloaks of wool, and they brought other new sheep skins which they were prepared to exchange for a piece of copper (Jane 1802:34).

It is not clear whether the wool was obtained from the same animal as the "sheepskins" or from dogs or whether the "sheepskins" may have been goat hides, dogskins, or, in fact, sheepskins. On another occasion, near Guemes Island, the account mentions trading for "a dogskin cloak decorated with feathers and a tanned skin" (Jane 1802:40). Further up the east coast of Vancouver Island, near Nanaimo, the ships were approached by 39 canoes carrying Indians who were wearing and trading wool cloaks.

> They also offered new cloaks, which we afterwards gathered were made of dog's hair, both because we could discover no difference in their texture from that of dog's hair and because in their settlements there were a large number of these animals, most of which had been shorn. They are of moderate size, apparently similar to English-bred dogs, very long-haired and generally white; among other characteristics which distinguish them from those of Europe is their manner of barking, which is no more than a miserable yelping (Jane 1802:48).

While exploring a large inlet of the continental coast along the Strait of Georgia, Valdés noticed a carved wooden plank depicting a standing human figure surrounded by five horned animals which appeared to be goats. Valdes named the inlet "Tabla Inlet" for the carved plank. Today called Toba Inlet, it is located in an area of the British Columbia coast where mountain goats are present in the Coast Range. Engstrand (1981) reproduces Cardero's drawing with the label "Tablet found on the east end of the Strait of Juan de Fuca," whereas Tabla or Toba Inlet is well north of what is presently regarded as the Strait of Juan de Fuca. This caption reflects some haziness in the definition of the strait's boundaries at the time of Spanish exploration, the first expeditions to chart these waterways. The Strait of Juan de Fuca was at first regarded by the Spanish explorers as one continuous passage extending through the waterways to the north of its present eastern end. This perception is illustrated by the summary statement regarding the 1792 expedition.

> We arrived at Nootka four months after we had set out from that harbor. ...When it had once been settled, as it was as a result of this exploration, that there was no passage to the Atlantic through the Fuca Strait, the gloomy and sterile districts in the interior of this strait offered no attraction to the trader, since in them there were no products, either of sea or land, for the examination or acquisition of which it was worth

> while to risk the consequences of a lengthy navigation through narrow channels, full of shoals and shallows (Jane 1802:89).

The subtitle of the account of the exploration—"the narrative of the voyage made in the year 1792 by the schooners *Sutil* and *Mexicana* to explore the Strait of Juan de Fuca"—also supports a broader view of the perceived boundaries of the Strait of Juan de Fuca. The explorations took place in the inland passage between Vancouver Island and the mainland. Hence, if the Spanish narratives of these explorations refer to the presence of wild goats along the Strait of Juan de Fuca, one possible explanation is that they encompassed that part of the British Columbia mainland where mountain goats are native.

Captain George Vancouver, 1792

The Spanish captains Galiano and Valdés encountered Vancouver's ships *Discovery* and *Chatham* on the night of 12 June in Birch Bay, and for about a month they pursued a joint exploration of the British Columbia coastline and islands. Vancouver had entered the Strait of Juan de Fuca on 29 April and had explored the Puget Sound area before heading north along the continental coast (Fig. B1). Like Eliza the year before, Vancouver also anchored in Discovery Bay and from there spent about 2 weeks exploring the length of Hood Canal with small boats. Regarding the fauna of the area, Vancouver observed that "The only living quadrupeds we saw, were a black bear, two or three wild dogs, about as many rabbits, several small brown squirrels, rats, mice, and the skunk, whose effluvia were the most intolerable and offensive I ever experienced." Among the birds Vancouver noted were "tern, the common gull, sea pigeon of Newfoundland [pigeon guillemot], curlews, sandlarks [sandpiper], shags [cormorant], and the black sea pye [oyster-catcher], like those in New Holland and New Zealand."

> Nor did the woods appear to be much resorted to by the feathered race; two or three spruce partridges had been seen; with few in point of number, and little variety of small birds: amongst which the humming birds bore a great proportion. At the outskirts of the woods, and about the water side, the white headed and brown eagle; ravens, carrion crows, American king's fisher, and a very handsome woodpecker, were seen in numbers; and in addition to these on the low projecting points, and open places in the woods, we frequently saw a bird with which we were wholly unacquainted, though we considered it to be a species of the crane or heron; some of their eggs were found of a bluish cast, considerably larger than that of a turkey, and were well tasted. These birds have remarkably long legs and necks, and their bodies seemed to equal in size the largest turkey. Their plumage is uniformly

> of a light brown, and when erect, their height, on a moderate computation, could not be less than four feet. They seemed to prefer open situations, and used no endeavors to hide or screen themselves from our sight, but were too vigilant to allow our sportsmen taking them by surprise. Some blue, and some nearly white herons of the common size were also seen (Meany 1907:119–120).

Vancouver's naturalist, Archibald Menzies, mentioned a couple of encounters with skunks, "a species of Diver" (probably a pigeon guillemot [*Cepphus columba*]) that burrowed into the sandy cliffs, black oystercatchers (*Haematopus bachmani*), and rhinoceros auklets (*Cerorhinca monocerata*). At Port Ludlow, Menzies observed that the Indians' clothing consisted of deer, lynx (probably bobcat), marten (*Martes americana*), and bear skins, and that one Indian "had a very large skin of the brown Tyger *Felis concolor* which was some proof of that Animal being found thus far to the Northward on this side of the Continent, but we saw very little of the Sea Otter Skins among them, which also shows that Animal is not fond of penetrating far inland" (Newcombe 1923:26–27). While in Puget Sound, he mentions trading for the skins of bear, lynx, raccoon, rabbit, and deer. Southeast of Port Townsend Menzies saw "a white animal...which we supposed to be a Dog about the size of a large Fox but it made off so quick into the woods that those who saw it were not certain what it was" (Newcombe 1923:25). This was probably a feral wool dog. On 31 May, off the coast near Everett he reported that "Some dogs had been left on shore on this Island whose yellings were heard several times in the night," but apparently he did not get a look at these dogs (Newcombe 1923:44). These were also probably wool dogs, which were sometimes kept on islands to prevent interbreeding with other village dogs (Shalk 1993).

Vancouver described wool dogs he observed near Port Orchard on Puget Sound:

> The dogs belonging to this tribe of Indians were numerous, and much resembled those of Pomerania, though in general somewhat larger. They were all shorn as close to the skin as sheep are in England; and so compact were their fleeces, that large portions could be lifted up by a corner without causing any separation. They were composed of a mixture of a coarse kind of wool, with very fine long hair, capable of being spun into yarn. This gave me reason to believe that their woollen clothing might in part be composed of this material mixed with a finer kind of wool from some other animal, as their garments were all too fine to be manufactured from the coarse coating of the dog alone. The abundance of these garments amongst the few people we met with, indicates the animal from whence the raw material is procured, to be very common in this neighborhood; but as they have no one domesticated excepting the dog, their supply of wool for their

> clothing can only be obtained by hunting the wild creature that produces it; of which we could not obtain the least information (Meany 1907:136).

Haeberlin and Gunther (1930) have stated that Indians of the Puget Sound region wove blankets of dog hair, mountain goat wool, and also a combination of feathers and fireweed fibers. The mountain goat wool was obtained from the Skykomish tribe to the northeast of Puget Sound where goats are found in the Cascade Range.

Further north along the Strait of Georgia, the explorers observed women weaving woollen blankets.

> In one place we saw them at work on a kind of coarse Blanket made of double twisted woollen Yarn & curiously wove by their fingers with great patience & ingenuity into various figures thick Cloth that would baffle the powers of more civilized Artists with all their implements to imitate, but from what Animal they procure the wool for making these Blankets I am at present uncertain; it is very fine & of a snowy whiteness, some conjectured that it might be from the dogs of which the Natives kept a great number & no other use was observed to be made of them than merely as domesticated Animals. Very few of them were of a White colour & none that we saw were covered with such fine wool, so that this conjecture tho plausibly held forth appeared without any foundation (Newcombe 1923:58).

The editor of Menzies' journal, C. F. Newcombe, notes that the following year, in June 1793, Vancouver and Menzies saw skins of the animal "from which the fine white wool comes" at a village near Bella Bella, on the British Columbia mainland coast, just north of Vancouver Island.

> It had small straight horns and was therefore supposed to be an unknown goat. The animal at this time was said to be high up in the mountains, but used to come down in winter. Menzies adds that at Nootka and Whannoh (i.e., the Nimpkish village) the natives were ignorant as to the animal "which they procured by barter from the natives inland." (Menzies' Journal, under date June 16th, 1793.) It was probably from this locality that Vancouver procured the mutilated skin which Richardson refers to under "Mountain-goat, Capra americana," in his Fauna Boreali-Americana, p. 268 (Newcombe 1923:154).

José Mariano Moziño, a Spanish naturalist stationed at Nootka, on Vancouver Island in 1792, also noted the use of mountain goat wool among the Indians who lived there, although mountain goats were not found on the island.

> Their dress is very simple. It commonly consists of a square cape woven from beaten cedar fibers and the wool of some quadruped, which I suspect to be a bison or mountain goat. They are provided with these by trade with the Nuchimanes, who perhaps have some commerce with the tribes of the continent where these beasts are found in abundance (Moziño 1970:13).

I. H. Wilson, translator and editor of Moziño's account, identifies the Nuchimanes as Nimpkish Kwakiutl who occupied a portion of the east coast of Vancouver Island as well as the mainland across from it.

United States Exploring Expedition, 1841

In 1838, the United States sent out six ships under the command of Lieutenant Charles Wilkes on an expedition to collect data and specimens in support of navigation, commerce, diplomacy, and science. During 1838–42, the expedition explored the coasts of South America, the Pacific Northwest, the South Seas, 1,500 miles of the Antarctic coastline, and other points of scientific interest. Titian Ramsay Peale, one of the expedition's naturalists, collected most of the mammal and bird specimens. John Cassin of the Academy of Natural Sciences in Philadelphia prepared the final report on the birds and mammals (Cassin 1858). The expedition explored the Puget Sound region during summer 1841. Wilkes's narrative of this exploration makes very little mention of wildlife. He reported that although the officers made several excursions into the woods at Port Discovery, no large game was seen, only "crows, robins, &c." and land snails (Wilkes 1845, 4:302). In the vicinity of Port Orchard, Wilkes commented that "The woods seemed alive with squirrels, while tracks on the shore and through the forest showed that the larger class of animals also were in the habit of frequenting them" (Wilkes 1845, 4:479).

Regarding the use of wool among the Native Americans of the area, Wilkes remarked that near Port Gardner (Everett), "The dress of the Sachet [Skagit?] does not vary much from that of the other tribes, and generally consists of a single blanket, fastened with a wooden pin around the neck and shoulders. Those who are not able to purchase blankets wear leather hunting-shirts, fringed in part with beads or shells, and very few are seen with leggings" (Wilkes 1845, 4:481). Apparently by this time, blankets were more often purchased than manufactured. However, at Neah Bay he noted the use of native blankets.

> Their dress consists of a native blanket, made of dog's hair interspersed with feathers: this is much more highly valued than the bought ones, but is rarely to be obtained (Wilkes 1845, 4:488).

Wilkes's narrative and the report on the mammal specimens collected by the expedition made no mention of mountain goats from the Puget Sound region.

Suckley, Cooper, and Gibbs (Pacific Railroad Surveys), 1853–1856

In 1853, Congress authorized a survey to locate a transcontinental railway route. Isaac Stevens, Governor of Washington Territory, led the expedition to explore a northern route between the 47th and 49th parallels. Dr. George Suckley and Dr. James Cooper served as surgeons and naturalists to parties of the expedition. George Gibbs was geologist and botanist for the party that included Cooper during its survey of the Cascades. These three naturalists did additional collecting in Washington state in areas of western Washington that were not on the original survey routes. Gibbs and Suckley collected in the Puget Sound region, including some locations on the Olympic Peninsula. In reporting on the mammals collected on the survey, Gibbs stated that mountain goats were common to both the Cascades and the Rocky Mountains. "The Yakimas and Snolqualme [*sic*] Indians get them in the Cascade Mountains, north of the Columbia, in latitude 47° 30′. They were formerly, if not now, abundant on Mount Hood" (Suckley and Gibbs 1860: 137). Suckley added that he

> obtained several hunters' skins of the mountain goat from the localities north of the Columbia River. ... Mr. Craig, an old Indian trader...says that these animals are quite abundant in the mountains near the Kooskooskia and Salmon rivers, streams which empty into Snake river, and that in the country of the Nez Perces...they are found in *great numbers* on the bald hills and bare mountains of that locality, and that upon these they can be seen from a great distance feeding in "large droves" (Suckley and Gibbs 1860:137).

Suckley also mentioned mountain goats having been collected in the Cascade Mountains north of Mount Rainier and from the upper Nisqually. He recounted having seen "dozens" of mountain goat skins in Indian lodges on Whidbey Island, northeast of the Olympic Peninsula, and stated that these skins were "obtained from the Indians living about Mount Baker, in the Cascade Range" (Suckley and Gibbs 1860:137). These reports do not include the Olympic Mountains in the range of mountain goats. Suckley, who lived in western Washington for 4 years, would probably have mentioned the presence of mountain goats in the Olympics if he had evidence or had heard reports of their being there.

Nineteenth-century Ethnographic Accounts

A number of nineteenth-century accounts of the lifestyle of Native Americans on the Olympic Peninsula mention the use of both mountain goat and dog wool. John Dunn, a Hudson's Bay Company employee, reported that the Clatset [Makah] Indians of Cape Flattery "manufacture some of their blankets from the wool of the wild goat" (Dunn 1845:157). Both Lieutenant Wilkes (1845) and George Gibbs (1877) in relating visits to Neah Bay at about the same time that Dunn wrote, reported that the Makah used dog wool in weaving their blankets. In addition to his survey of northwest mammals, Gibbs prepared a report on the Indian tribes of western Washington and northwestern Oregon, written in 1855 or 1856 but published posthumously in 1877 (Gibbs 1877). Gibbs reported that an 1850 visitor to Neah Bay had observed women weaving dog's hair blankets and that "the Indians of the Sound and the Straits of Fuca attained considerable skill in manufacturing a species of blanket from a mixture of the wool of the mountain-sheep and the hair of a particular kind of dog" (Gibbs 1877:174, 219). He described wool dogs as "of pretty good size, and generally white, with much longer and softer hair than either [the hunting dogs or the women's pets], but having the same sharp muzzle and curling tail as the hunting-dog" (Gibbs 1877:221). Gibbs also noted that "There are mountain-sheep or, more properly goats, in the higher parts of the [Cascade] range," hunted for their wool, which was "an article of trade" (Gibbs 1877:193, 220). He described far-ranging trade patterns extending across the Cascade Mountains for procuring wool and other commodities.

> The western Indians sold slaves, haikwa, kamas, dried clams, &c., and received in return mountain-sheep's wool, porcupine quills, the grass from which they manufacture thread, and even dried salmon, the product of the Yakama [*sic*] fisheries being preferred to that of the sound (Gibbs 1877:170; As is apparent from Gibbs' statement on page 193,cited above, Gibbs used "mountain-sheep" and "mountain-goats" interchangeably.[1] See Schalk [1993], for a further discussion of trade.).

Charles Pickering, anthropologist with the Wilkes Expedition, stated that the Chinook Indians, among whom he included all natives inhabiting the southern shore of the Straits, "weave blankets and belts, principally from the wool of the Mountain Goat (Capra Americana, *an animal said to be abundant to the northward*)" (Pickering 1895:17; emphasis added).

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[1] Anthropologist Dr. B. Lane suggests that Gibbs's confusing reference to "mountain-sheep or, more properly goats" may have resulted from an early (1855)—and later corrected—misidentification of the Nisqually word for mountain goat (s'weht-leh) with mountain sheep, which were also found in the Cascade Range (B. Lane, Victoria, British Columbia, personal communication, 1993).

Hubert Howe Bancroft (1875) cites an additional reference to wool blankets on the Olympic Peninsula:

> The Queniults [Quinaults] showed "a blanket manufactured from the wool of mountain sheep, which are to be found on the precipitous slopes of the Olympian Mountains" (Bancroft 1875:215–216, note 100).

The source of Bancroft's assertion is given as *Alta California*, 9 February 1861, quoted in *California Farmer*, 25 July 1862. (The original statement has not been located.) Ronald Olson, writing in 1936, based on interviews in 1925–27 with Quinault elders whose personal observations extended back to the mid-nineteenth century, stated that "the mountain goat and mountain sheep were unknown" to the Quinault Indians (Olson 1936:15; Schalk 1993:7–9).

Interior Exploration

Watkinson's Exploration, 1878

An account of an expedition that crossed the Olympic Peninsula in 1878 was sent by Eldridge Morse of Snohomish City to historian Hubert Howe Bancroft (Morse 1880). In September of that year, five young loggers led by Melbourne Watkinson hiked from Hood Canal to Lake Quinault and back again, taking 18 days for the round trip (Fig. B2). Morse's account was based on Watkinson's diary and additional information supplied to Morse by Watkinson. The adventurers traveled from Lake Cushman up the North Fork of the Skokomish River into high country, where they reported climbing a "steep mountain...about as high as Mount Olympus" and crossing over a divide into a river valley, presumably the East Fork of the Quinault. They reported shooting 1 elk and seeing others, including a band of 16, shooting 2 deer, seeing additional signs of elk and bear, and hearing wolves at night. Although the men traversed appropriate terrain, Watkinson did not mention mountain goats.

Governors' Reports, 1884 and 1888

Governors of Washington Territory submitted yearly reports on population, economic activity, agricultural production, resources, institutions, and various other territorial affairs to the Secretary of the Interior. The report of Governor Watson C. Squire in 1884 was notable for its listing of Washington's mammals and birds (Squire 1885). Among the 41 mammals mentioned was the mountain goat. Its range within the territory was not specified. Governor Eugene Semple included more information on some of the territory's larger game animals in a section titled "Information for Sportsmen" in his 1888 report.

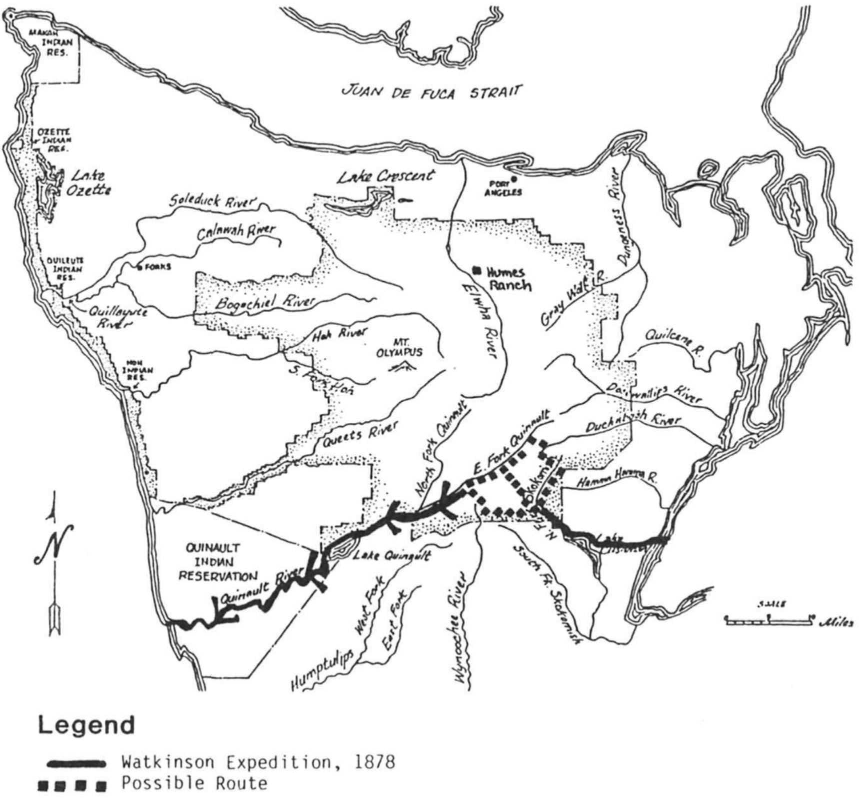

Fig. B2. Route of interior exploration by the Watkinson Expedition of 1878. From Evans (1983).

> A species of mountain goat, which very nearly answers the description of the ibex, is found near the snowy peaks between the lines of perpetual ice and timber. This is their habitat; they were not driven there by their enemies. They are gregarious, and, therefore, may be readily noticed in the distance, but they are difficult to approach. These animals exist in considerable numbers on the sides of Mounts Ranier [*sic*], St. Helens, and Baker, in the Cascade Range, and, possibly, may be found in other similar altitudes (Semple 1889:923).

Semple also included in his report a section on the Olympic Mountains, commenting that "it is a land of mystery...the interior is incognita" (Semple 1889:925–926). The Olympic Mountains had served as hunting grounds for peninsula tribes for several thousand years, and there had undoubtedly been occasional forays into the mountains by local homesteaders, hunters, trappers, and loggers since settlers began to reside on the peninsula in the mid-nineteenth century. But the resources of the peninsula's interior had remained essentially unreported and a subject of conjecture. Semple's romantic description of the interior's mystery inspired popular interest in exploration of the Olympics.

Gilman's Explorations, 1889–1890

An early venture into the Olympics was made in October–November 1889 by C. A. Gilman, a former lieutenant governor of Minnesota, and his son Samuel C. Gilman, a civil engineer (Fig. B3). The Gilmans left the Quinault Indian agency on the Pacific Coast on 20 October, traveled by canoe across Lake Quinault, and

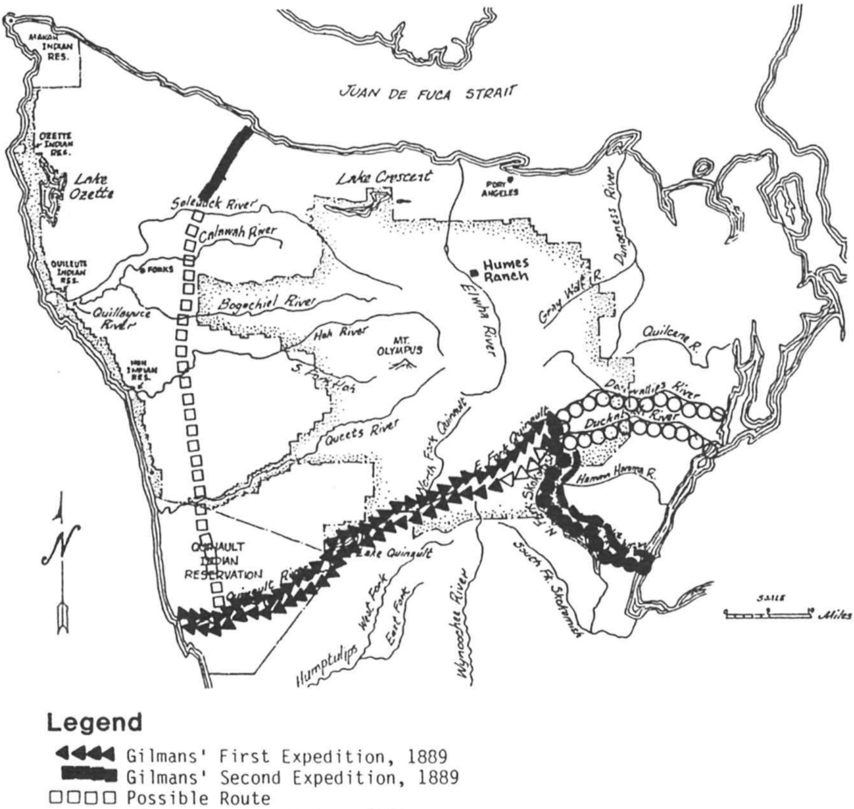

Fig. B3. Routes of interior exploration by both the Gilman and Wickersham expeditions of 1889 and 1890. From Evans (1983).

continued upriver, reaching the forks of the Quinault on 25 October. They followed the East Fork by canoe until they encountered a log jam, and then continued eastward on foot to within 2 miles of the foot of a mountain they identified as Mount Constance (but probably Mount Anderson). They reported climbing several peaks in the southeastern Olympics, but their exact itinerary wasn't detailed. In an account given later to a Seattle *Post–Intelligencer* reporter, they mentioned each of them shooting an elk and seeing many others, and their Indian guide killing four, but made no other wildlife observations. They returned to Grays Harbor on 27 November (Gilman 1890). A month later, the Gilmans again explored the west side of the Olympic Peninsula from the mouth of the Pysht River on the Strait of Juan de Fuca south to the Quinault River. They did not travel into the mountains on this second trip. In a brief report on the Olympic Peninsula based on these two excursions, Samuel Gilman's only mention of wildlife stated that "the streams teem with splendid fish and game is abundant" (Gilman 1890).

A more lengthy article about the Olympic Peninsula by Samuel Gilman was published in *National Geographic* in 1896. An editor's note at the beginning of this article states, "The following valuable article is based largely on the explorations of the writer in the comparatively unknown region he describes. A melancholy interest attaches to it, Mr. Gilman having been suddenly cut off, at the early age of thirty-six and in the midst of an increasingly useful and promising career, only a few days after the transmission of the article for publication and before he could be made aware of its acceptance" (Gilman 1896:133). This leaves open the possibility that the article may have been edited and altered, and that Gilman would not have been able to correct any inaccuracies. An inquiry to *National Geographic*'s Research Division failed to turn up the original manuscript or any other material relating to it. Gilman's posthumous article states

> Game is plentiful, and it would be a paradise for the hunter were it not so difficult of access. In addition to elk and bear, before mentioned, are deer, mountain goat, cougar, beaver, otter, fisher, wildcat, marmot, geese, ducks, grouse, partridge, quail, pelican, and many smaller or less desirable birds and animals (Gilman 1896:138).

Gilman does not state here that he personally observed mountain goats in the Olympics. This generalized summary of wildlife also includes "partridge," which are not found on the peninsula, although there are two species of grouse, and "quail," which is an introduced species.

Press Expedition, 1889–1890

In December 1889, a party of six led by James H. Christie, was organized under the sponsorship of the Seattle *Press* to explore the interior of the Olympic Mountains. Launching the expedition from Port Angeles, they entered the Elwha Valley and spent 4 months exploring that region until the unusually snowy winter was over. They then proceeded to the head of the Elwha Valley, crossed over Low Divide, and traveled down the North Fork of the Quinault to the Pacific Coast in May 1890 (Fig. B4). Christie and Charles Barnes, the expedition's historian, mentioned observing—and often shooting—elk, deer, wolf, wildcat, and bear, as well as seeing tracks of cougar and rabbit (Barnes and Christie 1890). A column titled "Found in the Olympics" that appeared over the name of C. A. Barnes in the 16 July Seattle *Press*, contained this summary of wildlife:

> The mountains are alive with elk, for the most time [*sic*] very tame. Some bands, however, having been out upon the foothills, and having probably been chased, are more wild. Deer are also plentiful. One goat was seen by the party. Grouse, pheasant and chicken are undoubtedly

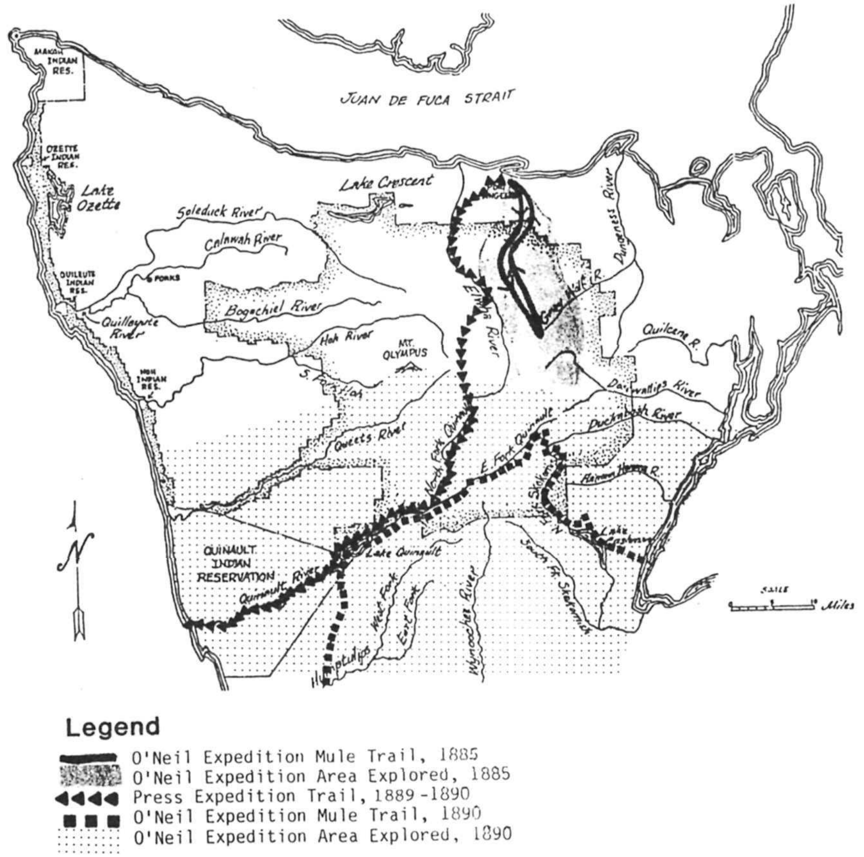

Fig. B4. Routes and areas explored by the Press (1889–90) and the O'Neil (1885 and 1890) expeditions. From Evans (1983).

> plentiful, although we saw few, owing to the severity of the season. Beaver and fisher are numerous on the Quinault. Black bear are plentiful during the proper season. We saw one track of a cinamon [*sic*] bear on the Goldie river. The cougar, or mountain lion, are numerous. We frequently saw their tracks, but never the animal himself. The grey wolf and the wildcat are common (Barnes 1890:20).

Barnes does not specify that it was a mountain goat, and, although he is presumably summarizing wildlife found in the Olympics, it is possible the explorers saw a free-ranging goat belonging to a settler in the Elwha or the Quinault Valley. He does not mention where or when or under what circumstances the goat was sighted. Nor is the observation of a goat recorded in his or Christie's diary narrative. The mention of chicken in the next sentence also gives cause to wonder whether Barnes is including domestic animals; there are no prairie chickens in the Olympics. Pheasant were introduced around 1881. Although "cinnamon" is today considered one of the brown color phases of the black bear, Barnes may have thought the bear track he mentioned belonged to a grizzly bear because of its size. There are only black bear on the Olympic Peninsula, and they all exhibit a black color phase.

O'Neil Expeditions, 1885 and 1890

Army Lieutenant Joseph P. O'Neil led two expeditions into the Olympic Mountains. In summer 1885, O'Neil and a small party spent nearly 6 weeks in the mountains south of Port Angeles. From Hurricane Ridge, one group explored the Elwha Valley while another proceeded along the ridge above the Lillian River (Fig. B4). From a base camp, probably in Cameron Basin, O'Neil and another soldier made a reconnaissance southward as far as the vicinity of Mount Anderson. O'Neil recounted hearing the screams of mountain lions close to their camp at night, shooting a marmot, seeing and shooting at several bear, shooting at one large wolf, and encountering numerous bands of elk in the high country (O'Neil 1890). On the route to Mount Anderson, O'Neil traveled through places that have subsequently become prime mountain goat habitat, but he reported none.

O'Neil returned to the Olympic Peninsula in July 1890 to lead a more ambitious expedition from Hood Canal across the southern part of the interior mountains. The expedition included three civilian naturalists: Louis F. Henderson, botanist, teacher, businessman, and graduate of Cornell University; Nelson E. Linsley, mineralogist; and Bernard J. Bretherton, field biologist and curator of the Oregon Alpine Club's museum. During this 3-month expedition, the enlisted men constructed a major mule trail across the southern Olympics, while small parties that included the naturalists fanned out in all directions to explore much of the southern half of the Olympic Peninsula, including an ascent of Mount Olympus (Fig. B4). O'Neil reported later on the wildlife observed:

> The game is very plentiful, particularly elk and bear; deer are somewhat scarce. ...All the large game seeks the higher altitudes during the midday, but may be found in the valleys morning and evening. ...Cougar are found in the foothills; I have seen none in the mountains. Beaver, mink, otter, and skunk abound in the valleys. The whistling marmot is found on the rocky mountains sides. A small animal much resembling him, called the mountain beaver, is found in soft places on the mountain sides (O'Neil 1896:19).

In September 1890, a small party, which included the naturalists Linsley and Bretherton and Private Harry Fisher, explored the vicinity of Mount Olympus. Bretherton and Fisher both kept journals. Bretherton's journal contains brief occasional entries. Fisher, who wrote with the idea of publishing, claimed to have kept notes of every day's events. His journal provides a much more complete account of the expedition. During this exploratory mission, Bretherton collected some bird specimens. Several bear were seen, and one was killed on 19 September "but no signs of other game. Elk nor deer had not been in this basin during the summer" (Fisher 1890:207). After climbing Mount Olympus on 22 September, Bretherton made his way down the Queets Valley, where he noted that sand bars along the river contained the tracks of elk, deer, bear, wolf, and otter, but none of these animals was seen. He saw a small beaver dam, shot a duck, and noted the presence of mink and weasels (B. J. Bretherton, Olympic National Park library, unpublished journal, 1890).

Private Harry Fisher's real name was James Hanmore. He had reenlisted under an alias to conceal a dishonorable discharge for drunkeness in 1889. Previous to that his character during a 5-year enlistment had been judged excellent. Fisher often accompanied the expedition's naturalists, took an interest in their observations, and apparently absorbed some of their knowledge of natural history. He described himself as "possessing some abilities as a botanist, mineralogist and assayer" and equipped himself with telescope, microscope, and compass, among other items. He developed a special interest in botany, and after being discharged from the Army in 1891, took up a land claim in the Queets Valley and collected botanical specimens. Fisher's detailed accounts of his activities regularly mention plants and animals observed or hunted in various locations, as in the following account for 7 August, in the high country near the headwaters of the Duckabush River:

> Descending into the basin, we examined the organic as well as the inorganic formation with one addition to our herbarium. This was the only spot at which I found watercress in mountain streams and these were very small. ...By perseverance we gained the divide again between the two streams. A very pretty and tall cone overlooked the country and we unstrung our packs and began its ascent. Upon this

> peak I collected two plants in flower that were entirely strange to me. Leveling the glass I could distinctly make out a deer in the lake playfully splashing water. Further on was the lone calf and higher up was bruin who I have no doubt added this calf to his greed before morning. Completing our sketches we descended to our packs. While adjusting our paraphernalia, a deer was sighted descending below us. Thinking we might find a good route down into Elk basin we allowed it to go undisturbed and followed its trail. While passing over a damp spot a strange wild onion was discovered. Silver skin and of peculiar shape, white blossom and odor was natural. The bulbs grew in clusters as in artichokes, firm and very rich in albumen. ...A greater portion of the timber was dead at this alt. (perhaps fire had spread). ...Melting snow from above created a dampness in the soil which was burrowed as thoroughly as a prairie dog town. The inhabitants were a mystery. Marmots were bold and inhabited dry and rocky slopes, generally the track of a rock slide, while these animals chose wet places, frequently irrigating their holes by digging ditches. Their holes were much smaller than the marmot and none of them were ever sighted. We called them mountain farmers from the fact that they gathered grass and herbs, distributing them in regular and even bunches upon logs and rocks to cure. This was done at night and taken in when cured. Whether mountain beaver, wood rats or a species of the marmot we were unable to decide accurately (Fisher 1890:97–99).

Fisher made extensive excursions through areas that are presently inhabited by introduced mountain goats. He stated that he "had kept a vigilant look out for goat and sheep," and was "satisfied that neither are to be found in this range of mountains" (Fisher 1890:217).

> The large game of the mountains were elk, bear, of the black species only, white and black tail deer. Along the streams were cougar, otter, beaver, raccoon, mink, wild cat and perhaps wolves but none were sighted by our party. Among the ground animals were the marmot...and the smaller mountain farmer, perhaps a mountain beaver, whose habits and appearance we learned but little of. Chipmunks were plentiful and some gray squirrels. All varieties of grouse were represented but no pheasant (Fisher 1890:217).

Fisher reported both white and black-tailed deer. Although white-tailed deer do not occur now on the peninsula or in the Puget Sound lowlands, small populations occurred historically (Suckley and Cooper 1860). A white-tailed deer specimen (serial no. 00067407) taken by C. P. Streator on 4 July 1894 at Lake Cushman is in the National Museum of Natural History. The closest extant white-tailed deer population occupies a small area on the lower

Columbia River. Although the two squirrels commonly found in the Olympics are Douglas squirrel (*Tamiasciurus douglasii*) and northern flying squirrel (*Glaucomys sabrinus*), Fisher could have seen gray squirrels (*Sciurus griseus*) in the southern part of the peninsula where there were oak trees.

O'Neil's second expedition explored areas in the eastern Olympics that have supported high densities of mountain goats in recent years. As Governor Semple and early naturalists observed regarding the mountain goats in the Cascades, these large white animals are "gregarious...and readily noticed in the distance." It seems likely, therefore, that if goats had been present, Fisher, keeping a "vigilant lookout" with his telescope over a period of 3 months, would have spotted some.

James Wickersham's Excursions, 1889 and 1890

Not much is known about Judge James Wickersham's trip into the Olympics in the summer of 1889, although the Seattle *Press* reported in its 16 July 1890 issue that Wickersham and another man had traveled about 20 miles up the Skokomish River (Fig. B3). Wickersham, however, did leave an account of his outing into the eastern Olympics during July and August 1890. His party, which consisted of friends and family members, took 20 days to cover what he estimated to be a 125-mile trip into the upper reaches of the Skokomish, Duckabush, and Dosewallips watersheds. Wickersham specifically mentioned seeing and killing a marmot, seeing a bear and cub and killing the bear, and estimated that there were 300 elk (a low estimate) remaining in the Olympics, as well as deer. He generalized

> Bear, elk, deer, and cougar, wild cat, beaver, and many smaller animals are numerous, while the streams and lakes are filled with trout and salmon—a veritable hunter's and fisherman's paradise (Wickersham 1961:13).

After spending 3 weeks climbing peaks in the eastern Olympic Mountains and camping in high mountain meadows in areas now inhabited by numerous goats, Wickersham did not mention observing mountain goats.

Other Explorations, 1880's–1890's

As the Press Party expedition of 1889–90 was being dramatized in the Seattle *Press*, other Puget Sound area newspapers capitalized on the popularity of Olympic exploration and reported on various expeditions into the mountains. Norman R. Smith, a Port Angeles resident who had accompanied O'Neil's 1885 expedition into the foothills of Mount Angeles, was reported to have done surveying for possible railroad routes from Clallam Bay to Quillayute (La Push) and from Port Townsend to Union City in 1882. He reportedly explored from Quilcene Bay into the Jupiter Hills in 1881 and from time to time was reported to have made other explorations in "innumerable directions." According to Smith,

> The principal game is elk, deer and black bear. There are also the panther, cougar, mountain lion and an occasional wolf. There used to be very many wolves, but they have nearly all been poisoned by the settlers (*Seattle Post–Intelligencer* 1890).

John Conrad gave an account of the explorations of five prospectors who spent 24 days exploring the Olympics. The account is based on a diary kept by A. D. Olmstead who, along with Conrad, was one of the five. Their trip began on 19 June, shortly before O'Neil's second expedition. Beginning on the east side of the peninsula, they hiked up the Dosewallips River valley, followed the divide between the Dosewallips and the Elwha watersheds, and descended into the Elwha Valley where they came upon the Press expedition trail, which they followed out of the Olympics. They reported abundant bear, cougar, elk, deer, "woodchucks," and grouse, and killed four bears, five elk, and five deer. They did not mention mountain goats (Conrad 1890).

In July 1896, a party consisting of Frank Reid, Roland Hopper, Edward Munn, and Fred Church, who had accompanied the O'Neil 1890 expedition, traveled the O'Neil trail from Hood Canal to the Pacific. They built a cabin near Marmot Lake at the head of the Duckabush (about 1,371 m) and camped there for 3 weeks. They shot elk, bear, and a fisher and also reported deer and blue grouse. In the Quinault Valley they noted signs of bear, elk, and cougar "everywhere" but didn't see any game. They did not mention mountain goats (Anonymous 1896).

Also in July 1896, a party of five left Lake Cushman and followed the O'Neil trail up the Skokomish Valley to the divide between the Skokomish and the Duckabush drainages, where they camped for a week before moving to a camp at Marmot Lake. From these camps they made several exploratory trips, including one into the Quinault Valley, and one attempting to locate a route down the South Fork Skokomish River. They reported seeing bands of elk, shooting one, and seeing signs of deer, bear, wolf, and cougar. They saw many marmots and, in the Quinault Valley, a beaver (*Castor canadensis*). While camping, they ate grouse. They did not mention mountain goats (Maring 1898).

The Mountaineers, 1907

In 1907, and again in 1913, 1920, and 1926, the Mountaineers of Seattle organized outings into the Olympics. In late July 1907, a large group of more than 60 hikers set out to climb all three peaks of Mount Olympus and several members reached the summits. Preparations for, and accounts of, this excursion were extensively written up in the Mountaineers' publication, as were descriptive accounts of the Olympics in succeeding issues of the *Mountaineer*. The club's outings involved cross-Olympic hikes following the Press and O'Neil trails and ascents of peaks in the Olympic range. None of the articles provided extensive wildlife observations. Animals mentioned are deer, bear, cougar, and elk. An article appearing in the *Mountaineer* just before the Mountaineers' 1907 expedition summarizes other explorations of the Olympics and mentions that one goat was seen by the Press Party in 1890, citing Barnes's summary in the 16 July 1890 Seattle *Press* (Hanna 1907).

Observations by Local Residents, Naturalists, and Recreationists

Several residents of the Olympic Peninsula who were closely acquainted with the natural resources of the mountains and forests during many years have provided valuable published and unpublished accounts of the wildlife.

Grant and Will Humes, 1897–1934

The Humes brothers maintained a homestead on a bench above the Elwha River near Idaho Creek and made a living by hunting, trapping, and guiding and packing into the Olympics for recreational parties. Will moved back to New York State around 1916, while Grant remained in the Elwha Valley for the rest of his life (until 1934). Will and especially Grant wrote long, descriptive letters about their seasonal activities, hunting and commercial guiding trips into the mountains, wildlife observations, and tallies of animals trapped or shot by them and other area hunters and trappers such as Billy Everett and Dewey Sisson. Grant sometimes hunted on commission for specimens of particular game animals. His letters mention hunting and trapping cougar, bear, elk, deer, bobcat, wolf, marten, fisher, mink (*Mustela vison*), raccoon (*Procyon lotor*), and skunk—most of the major game and furbearing mammals on the Olympic Peninsula. The Humes brothers made many trips into the interior mountains to hunt and trap and to guide and pack for sportsmen, including trips to Mount Olympus in 1905, 1907, and 1919. They constructed many of the trails in the Elwha Valley. Grant Humes probably knew the terrain and animals of the Olympics as well as anyone could at that time and was a keen observer of nature, a photographer, and an articulate writer of descriptive accounts of what he saw. During his almost 35 years of living and traveling in the Olympic Mountains, he did not mention having seen or heard of a mountain goat in any of a collection of 132 letters (Grant W. Humes, Olympic National Park library, unpublished letters, 1897–1934).

Albert B. Reagan, 1905–1909

Albert Reagan was an Indian agent and school teacher from 1905 to 1909 at La Push at the mouth of the Quillayute River on the Pacific Coast. He held a bachelor of science degree from Valparaiso University and bachelor and master of arts degrees from the University of Indiana. Years later, after retiring from the Indian Service, he earned a Ph.D. in geology from Stanford University. While living on the Olympic Peninsula, he wrote several scholarly and popular articles on ethnographic, archaeological, and natural history subjects. In 1908, Reagan wrote a lengthy article on the natural history of the Olympic Peninsula. He listed the game animals of the Peninsula as follows:

> In this region is to be found an abundance of game. Deer and elk are plentiful; wildcats, panthers and black bears are numerous; ducks and pheasants stay throughout the year, and the islands of the coast swarm with sea fowl; and the finest salmon and trout on the coast abound in the numerous streams (Reagan 1909b:137).

Reagan made a more inclusive list of animals of the Olympic Peninsula, based on 3 years of observation "as time would permit" in the high country around the headwaters of the Soleduck River and in the Happy Lake area, as well as in lowland and coastal areas (Reagan 1909a): Douglas squirrel; Townsend's chipmunk; another chipmunk, *Tamias caurinus* Merriam; Olympic marmot; flying squirrel; mountain beaver; a mouse, *Peromyscus akeleyi* Elliot; wood rat; another mouse, *Erotomys nivarius* Bailey; three species of vole; gopher; kangaroo mouse; shrew; "Washington rabbit," *Lepus washingtoni* Baird; Roosevelt elk; black-tailed deer; bobcat; coyote; gray wolf; black bear; fisher; pine marten; mink; two species of weasel; river otter; spotted skunk; striped skunk; mole; rat; sea otter; sea lion; and hair seal. He did not list mountain goat.

However, Reagan did include mountain goat among animal, fish, and plant remains found in coastal middens in the vicinity of La Push. He listed among the bones of animals identified "elk, big horn, mountain goat, black bear, *Putorius*, species?, black-tailed deer, wild cat, beaver, raccoon and otter" (Reagan 1917:16). He stated in a footnote that the remains of the bighorn sheep and mountain goat "are found usually only in the ladle form of the horns," suggesting that these manufactured items were probably acquired by the Indians through trade (see Schalk 1993:21–22).

Chris Morgenroth, 1890–1927

Chris Morgenroth homesteaded in the Bogachiel Valley in 1890. He began working for the Olympic Forest Reserve in 1903 and continued with Olympic National Forest until 1927. During the earlier years and while working for the

Forest Service, Morgenroth explored and hunted over much of the Olympic Peninsula. The Seattle *Post–Intelligencer* on 24 February 1913 described Morgenroth as someone who "knows every nook and corner of the Olympics" (Morgenroth 1991:127). In an autobiography published by his daughter, the forest ranger related many of his experiences in the Olympics, including hunting trips, observations, and encounters with wildlife. In this material, he never mentioned the presence of mountain goats in the Olympics before their introduction. In fact, for many years before their introduction, he had advocated bringing either mountain sheep or mountain goats into the Olympics. In 1908, Morgenroth prepared a summary report on Olympic National Forest. In a discussion of game animals he included elk, deer, grouse, pheasants, black bear, wild cats, wolves, cougars, and "a large variety of smaller fur bearing animals." In this report, he suggested, "It would be advisable to stock the forest with a few mountain sheep[;] they would undoubtedly thrive in the higher altitudes" (Morgenroth 1908:20). It is unlikely he would have made such a comment if mountain goats already inhabited the Olympic Mountains. When goats were introduced in 1925, Morgenroth was one of the individuals present at their release near Mount Storm King.

E. B. Webster, 1910's–1920's

Edward B. Webster was a Port Angeles resident, newspaper publisher, and avid outdoorsman. In 1917, he estimated that since 1900 he had made 220 trips to timberline in the Olympics, 176 of which had been to the summit of Mount Angeles (Webster 1917). Many of the trips had been for 1, 2, or 3 weeks each. In 1920, Webster published a book on the mammals of the Olympic Peninsula. The book won high praise from naturalists, including C. Hart Merriam, former chief of the U.S. Biological Survey. Webster stated positively that "the fauna of the Olympic Mountains...has never included the Mountain Goat" (Webster 1920:146). While Webster was its president, a local hiking group—the Klahhane Club—supported the introduction of mountain goats and the establishment of a game sanctuary on Mount Angeles, in part to provide a home for the goats once they were introduced, though they were not initially released there. Webster (1925, 1932) published articles documenting the introduction and subsequent observations of mountain goats on the Olympic Peninsula.

Leroy Smith, 1910's–1950

Leroy Smith, a long-time resident of the Olympic Peninsula, wrote an account of pioneering on the peninsula. He described early hunting and trapping experiences extending over about 35 years. He related having hunted most of the major mammals on the peninsula and did not mention the presence of mountain goats (Smith 1977).

Essays on mountain goats and mountain goat hunting appear in late nineteenth–early twentieth-century books and periodicals on natural history, sport hunting, and recreation. Several are by authors such as James C. Merrill (1880); John Fannin, curator of the Provincial Museum in Victoria, British Columbia and George Bird Grinnell (Fannin and Grinnell 1890); William T. Hornaday (1904), director of the New York Zoological Park; and Ernest Thompson Seton (1909). The mountain goat was known to inhabit the Rocky Mountains of western Montana, eastern Idaho, and British Columbia, the Cascade Range in Washington, and the Coast Range of British Columbia and Alaska. None of the many references searched mentioned the possibility of observing or hunting mountain goats in the Olympic Mountains. Madison Grant stated

> The true *Oreamnos montanus* extends from about the Canadian boundary, south through Washington and into Oregon. In the '70's a considerable number were found on Mt. Ranier [*sic*] in Washington, and they still occur on Mt. Baker to the northward. It is absent, however, from the Olympic Mountains, from Vancouver Island and from the southern Cascades in Oregon (Grant 1905:236).

Biological and Administrative Surveys

Clark P. Streator, U.S. Department of Agriculture, 1894

In June and July 1894, Clark P. Streator of the U.S. Department of Agriculture Division of Ornithology and Mammalogy, spent 3 weeks collecting mammals in the Lake Cushman area. He mentioned a trip to Mount Ellinor, where he heard marmot whistles amidst craggy terrain and caught a marmot in a snow basin. He made notes on whether animals reported to be present were common or not, noted signs and other evidence of animals he did not actually see, mentioned shooting a deer and a bear, and reported that he did not see any elk (U.S. Fish and Wildlife Service, Smithsonian Institution Archives, Box 103, Record Unit 7176, unpublished 1860–1961 field reports). He did not mention mountain goats.

Bernard J. Bretherton, U.S. Department of Agriculture, 1894

Bernard J. Bretherton, who had been a naturalist on Lieutenant O'Neil's 1890 expedition, returned to the eastern Olympics in August–September 1894 as a collector for the U.S. Department of Agriculture. Bretherton's month-long itinerary is not well detailed; his journal notes are mainly a listing of small mammal specimen numbers and measurements. He followed the O'Neil route along the North Fork of the Skokomish River, going as far as 3 miles northwest of Mount Steel, to an elevation of about 1,500 m. He noted locations where he trapped a mountain beaver and a marmot "kitten" and altogether collected almost 90 specimens of small mammals and birds (B. J. Bretherton, Olympic National Park library, unpublished collector's records, 1890–98). Part of his route passed through habitat now occupied by goats. Bretherton made no mention of seeing any large mammals on this trip.

C. Hart Merriam and Biological Survey Members, 1888 and 1897

Clinton Hart Merriam was the first chief of the U.S. Biological Survey (which later became the Fish and Wildlife Service), and for 25 years he directed the course of investigations of North American mammalian fauna. Merriam developed the concept of "life zones" represented by characteristic communities of plants and animals that varied with changes in altitude in mountainous areas. Description of these life zones became the mission of the Biological Survey under Merriam.

In 1888, Merriam spent about 2 weeks in the Puget Sound area observing and collecting small mammals and birds near Port Townsend and Neah Bay on the Olympic Peninsula and visiting the Provincial Museum in Victoria. He spent from 31 August to 4 September at Neah Bay, wandering in the woods, setting traps, and querying residents about the local fauna. There he noted the presence of *Ursus americanus* (black bear), *Mephitis* (striped skunk), *Spilogale interrupta* (spotted skunk), *Lutra canadensis* (river otter), *Lutreola vison* (mink), *Putorius* (*longicauda*?; long-tailed weasel), *Sorex* (shrew), *Sciurus douglasi* (Douglas squirrel), *Tamias townsendi* (Townsend chipmunk), and *Hesperomys arcticus* (white-footed mouse). Merriam also made notes in his field journals of what species were not present at locations he visited. He mentioned that "there are no Porcupines, Muskrats, or Rats near Neah Bay, and the Indians do not know any such animals. Deer and Elk occur a few miles back in the deep forests. Caribou are not known on this side of the Strait" (C. Hart Merriam, Papers of C. Hart Merriam–Box 4, Manuscripts Division, Library of Congress, unpublished journal, 1888:51).

Merriam visited the Olympic Peninsula again during the last week in August 1897, accompanied by Vernon Bailey, a member of the Biological Survey. Merriam and Bailey traveled up the Soleduck Valley in the northern Olympics to an estimated elevation of about 1,400 m, just below High Divide in Seven Lakes Basin. They camped in this area for 3 nights and collected specimens of marmots, chipmunks, and mice; explored the head of the Bogachiel Valley; shot at a bear and her two cubs near their camp; and also observed an *Aplodontia* (mountain beaver) colony not far from camp. Merriam did not see any elk, although he saw trails and plenty of tracks. Merriam had seen several heads and a few hides of Olympic elk while in the region and made arrangements with local hunters to secure specimens for him later in the year after the elk had put on winter pelage. A specimen sent to him from the Olympic Peninsula later that year became the type specimen for the Roosevelt elk (Merriam 1897). Merriam noted in his field journal that animals "said not to occur in the Olympics are Sheep, Goats, Porcupines, Coyotes, Foxes, Grisly [*sic*] Bear" (C. Hart Merriam, Papers of C. Hart Merriam–Box 6, Manuscript Division, Library of Congress, unpublished journal, 1897:36).

Merriam, having spent 2 weeks at Mount Rainier before coming to the Olympics, was interested in the differences in plants and animals found in these two locales. Merriam's papers at the Bancroft Library include several pages of notes listing plants and animals that he found on Mount Rainier but did not find in the Olympics. In a typed manuscript, Merriam explored the reasons for these differences:

> The gap that separates the Olympic Mountains from the Cascade Range, the only other mountains of the region, is only about a hundred miles wide and is filled by the dense forest already mentioned, affording continuity of range for species inhabiting the mixed Transition and Canadian zones, but the higher parts of the Olympics, falling within the Hudsonian and Alpine zones, have been disconnected from corresponding zones to the north and east for at least several million years, a period long enough to admit a considerable amount of differentiation in the species stranded here. ...Contrasting the faunas and floras of the two regions, some highly interesting differences appear. The flora of the Olympics is rich and varied and comprises a number of types not known from the Cascade Range. The fauna, on the other hand, at least as far as the land vertebrates are concerned, is rather meagre and is not known to include a single specific type not found in the Cascades. ...Among mammals, perhaps the most striking peculiarity of the region is the species it lacks. There are no Mountain Sheep, Goats, Porcupines, Coyotes, Foxes, or Grizzly Bears in the Olympics (Merriam, undated manuscripts "The Olympic Forests" and "The Olympic Mountains").

Merriam's papers at the Bancroft Library contain a popular article on the mountain goat authored by Merriam (the periodical in which it appeared is not identified) and an article by him on the taxonomy of the mountain goat (Merriam 1895) showing Merriam's particular interest in this animal. The popular article identifies the range of the mountain goat as extending from the Rocky Mountains in Idaho and the Cascades in Washington north through British Columbia and the coast ranges of Alaska to the Kenai Peninsula. It does not include the Olympic Peninsula.

In May and June 1897, Edward A. Preble and R. T. Young of the U.S. Biological Survey also visited the Olympic Peninsula. Their observations and collecting activities, however, were confined to birds and small mammals on the western side of the peninsula, in the vicinity of Neah Bay, La Push, and Quinault.

Field Columbian Museum Expedition, 1898

In July 1898, a party from the Field Columbian Museum (Field Museum of Natural History) of Chicago arrived to spend about 3 months collecting animal specimens in the Olympics. They particularly wanted to find Roosevelt elk in their summer range in the interior mountains. They camped in the Elwha Valley, then spent 3 weeks at Happy Lake collecting mainly small mammals before moving to the vicinity of nearby Boulder Lake, at an elevation of about 1,300 m. "The summits on the south of this lake were so broken by jagged ridges, impassible [*sic*] ravines, snowfields of uncertain depths and yawning chasms, that progress in any direction was out of the question" (Elliot 1899:245)—that is, it was good mountain goat habitat. They also visited the upper Soleduck Valley and the Bogachiel Valley where they obtained five specimens of elk. Altogether the expedition collected between 500 and 600 specimens, "with few exceptions embracing all the species known to inhabit the region," including elk, deer, and bear (Elliot 1899:246). D. G. Elliot, curator of mammals, described 30 species and subspecies of mammals from the Olympic Mountains. The mountain goat was not included nor was it mentioned as one of those few exceptions. Elliot, like Merriam, demonstrated a special interest in the mountain goat, describing the Alaska form of the goat as a new species in 1900 (Elliot 1900).

State of Washington, 1898

In 1898, the state fish commissioner (who was also the ex officio state game warden) reported on the status of ungulates in western Washington, listing deer, elk, mountain sheep, and mountain goats as present in the Cascade Mountains and only deer and elk as present in the Olympic Mountains.

> The section within the limits of the Cascade mountains and contiguous territory contains great numbers of several varieties of deer and a limited number of elks, mountain goats, and mountain sheep. The western part of the state, within the section embraced by the Olympic mountains and its spurs, contains a great many elks and deer of several varieties (Little 1898, cited in Schullery 1984:38).

U.S. Geological Survey and U.S. Forest Service, 1897–1925

In 1897, much of the Olympic Peninsula was set aside in the Olympic Forest Reserve. During 1898–99, Arthur Dodwell and Theodore Rixon surveyed the reserve, but the focus of their report was topography and soils and especially the types and quantity of timber found on the Olympic Peninsula rather than wildlife

(Dodwell and Rixon 1900). The Olympic Forest Reserve became Olympic National Forest in 1907. Ranger Chris Morgenroth (see above) prepared a report (1908) enumerating the major types of game animals in Olympic National Forest, which did not include mountain goats. U.S. Fish and Wildlife Service biologist Victor B. Scheffer compiled an "estimated wildlife census" of mammals in Olympic National Forest based on figures reported by rangers in annual wildlife reports beginning in 1918. No mountain goats were sighted until two goats were listed in 1929, 4 years after the first release of goats (Scheffer 1949). Scheffer included mountain goats among 11 species of mammals that, although they were found in the Cascades and might logically be expected to occur also in the Olympics, were not present because the intervening lowlands of Puget Sound have presented a barrier to their dispersal since the end of the last glaciation. Scheffer noted, however, that goats had been introduced more recently by sportsmen and game managers.

U.S. Biological Survey, 1917–1921

From 1917 through 1921, several members of the U.S. Biological Survey carried out investigations in Washington State (Hall 1932). In 1918, Vernon Bailey visited the Olympic Mountains in April and May, stopping in the Elwha Valley at Humes ranch and hiking up the Hoh Valley. In 1921, Walter P. Taylor and George C. Cantwell (who had been custodian of the federal bird refuges off the coast of the peninsula), William T. Shaw, Harold St. John (of Washington State University), and W. G. Cassels spent from late June until early September exploring the Olympic Mountains, visiting the Elwha Valley, Hurricane Ridge, Happy Lake and Boulder Lake, the headwaters of the Elwha, Dosewallips, and Quinault rivers, and the Soleduck and Hoh valleys. Their itinerary included 5 days above timberline at the head of Little River and on Hurricane Ridge and 5 days in the vicinity of the headwaters of the Dosewallips, both areas that have recently been frequented by goats. Bailey, Taylor, and Cantwell submitted reports on the mammals of the Olympic Mountains. Taylor's field report lists 40 species of animals observed in the Olympics, including notes on where they were seen or collected. It also included where they were seen or taken by local informants, including their packer, Oscar Peterson, Billy Everett (who owned Olympic Hot Springs), Chris Morgenroth (forest ranger), Grant Humes, William Stewart (U.S. Forest Service fire guard and "veteran trapper"), and E. B. Webster, all of whom knew the Olympics intimately (USFWS circa 1860–1961, Box 104). Cantwell's report discusses 37 (mostly the same) species (USFWS circa 1860–1961, Box 100). None of these reports mentions mountain goats in the Olympics.

W. P. Taylor was familiar with various locations of mountain goats in Washington State. In 1919, Taylor made extensive wildlife observations on Mount Rainier. His field notes contained lengthy observations on mountain goats, including not only goat sightings but also observations of goat tracks, droppings, and trails (USFWS circa 1860–1961, Box 104). J. B. Flett, Mount Rainier naturalist, told Taylor about other areas in western Washington where he had observed goats, mentioning Mount St. Helens and Goat Rocks. Flett had made his first trip into the Olympics in 1897, and he recounted bear observations in the Olympics to Taylor. It seems likely that if Flett had observed goats in the Olympics, he would also have related this information to Taylor. Also, given the thoroughness of Taylor's goat observations on Mount Rainier, it seems likely that if there had been any traces of mountain goats in the Olympics, he would have noted them. Taylor and Shaw (1929) defined the range of the mountain goat in Washington State as the Cascade Mountains north to the Canadian border, south at least to Goat Rocks, east to the vicinity of Lake Chelan, and west to Mount Baker and Mount Rainier. The subspecies, *Oreamnos americanus missoulae*, was reported to have once occurred in the Blue Mountains in the southeastern part of the state, but W. Dalquest expressed the opinion that this report was based on a misidentification (Dalquest 1948:406).

F. M. Gaige, 1919

In July and August 1919, F. M. Gaige of the University of Michigan–Walker Expedition collected 131 mammal specimens in the vicinity of Lake Cushman, including a few that were collected on a short trip to Mt. Steel. Gaige collected only small mammals. Most were taken near the post office at Lake Cushman at an elevation of about 174 m (Dice 1932).

State of Washington, 1938–1940

In its fourth biennial report, the Washington State Game Commission stated that a study of mountain goats had been conducted during the biennium by a department biologist. "Previously the Department had little conclusive data available on the habits, habitat and rate of reproduction of this animal" (Washington State Game Commission 1940:72). The mountain goat study, written by Niilo A. Anderson, states

> No mountain goats are native to the Olympic Mountains, but two forms have been planted there and are reported to be increasing in numbers. Of these, four animals of the form *Oreamnos americanus columbiae* were introduced from Banff, Alberta, in 1924 [1 January 1925], and eight animals of the *Oreamnos americanus kennedyi* group were introduced from Alaska and released in 1929 and 1930 (Anderson 1940:2).

For an account of the introduction of mountain goats into the Olympic Mountains and their subsequent dispersal, see Webster (1925, 1932) and Moorhead and Stevens (1982).

Discussion

Historical records of wildlife observations on the Olympic Peninsula include conflicting reports concerning the presence of mountain goats. Spanish explorers (Wagner 1933), Gilman (1896), and a newspaper summary of the Press Expedition (Barnes 1890) mentioned that goats were present. In addition, several nineteenth-century observers (Dunn 1845; Wilkes 1845; Bancroft 1875; Gibbs 1877; Pickering 1895) as well as the Spanish explorers (Jane 1802) and Vancouver (Meany 1907) mentioned the use of mountain goat wool by Native Americans in the Puget Sound region. On the other hand, at least four other pre-1925 discussions of Olympic Peninsula wildlife (Fisher 1890; Merriam 1897b; Grant 1905; Webster 1920) state positively that goats were not present. Three of these authors had explored the Olympic Mountains. Early naturalists describing the known range of mountain goats in North America do not include the Olympics (e.g., Fannin 1890; Hornaday 1904; Seton 1909). Several biologists writing about Washington mammals after the 1920's state that mountain goats were introduced to the Olympic Mountains (Anderson 1940; Scheffer 1949; Johnson 1983). The remainder of the reports by recreationists and wildlife biologists that list Olympic mammals do not include goats.

However, because goats were not mentioned in the majority of cases, it does not logically follow that they were not observed or were not present. To assert this would be to succumb to the "fallacy of negative proof"—claiming that because these observers provided no evidence of goats, they prove that goats weren't there (Fischer 1970). Nevertheless, the considerable amount of negative—or null[2]—evidence (failures to mention goats among mammals observed in the Olympics) does not lack significance. By examining the thoroughness, quality of, and reasons for the observations of those who do not mention goats, a reasonably accurate assessment can be made of whether or not such observers would have mentioned goats if they had noticed them and how likely it was they would have have seen them if, in fact, goats had been present. Thus, in comparing and assessing the relative reliablility of the various reports, it is necessary to consider carefully (1) the training and experience of the observers, (2) their familiarity with the region and purpose for exploring it, (3) the extent and thoroughness of their exploration activities and opportunities, (4) their familiarity with the habits of wildlife, particularly mountain goats, and (5) the informational detail provided in their observations. When all such factors are considered, some of the observations clearly assume more credibility than others.

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[2] Anthropologist Dr. B. Lane suggested that the term "null evidence" for an absence of information is more accurate than "negative evidence" as used by Lyman (1988:15; B. Lane, Victoria, British Columbia, personal communication, 1993).

The initial references to "wild goats" reported by the Spanish explorers are problematic for several reasons. Manuel Quimper, who provided the first account of an exploration of the Strait of Juan de Fuca, stated that "buffalo, stags, deer, wild goats, bears, leopards, foxes, hares, and rabbits feed on their luxuriant pastures" on the south side of the strait (Wagner 1933:128). Quimper anchored for a while at Dungeness and stopped briefly at Freshwater Bay and Neah Bay. No inland explorations were attempted. Because mountain goat habitat in summer is in high rocky areas above timberline, it is highly unlikely that Quimper actually saw mountain goats along the coast. The following summer, Eliza merely confirmed that "all the animals are also found which occur in the description of the Estrecho de Fuca by Don Manuel Quimper" (Wagner 1933:151). Likewise, Pantoja's general statement of animals present is essentially a repetition of Quimper's: "On both coasts, particularly on the shores, different kinds of pasture are very common on which feed buffalo, stags, deer, wild goats, hares and rabbits" (Wagner 1933:184).

In addition to the unlikelihood of seeing mountain goats grazing near sea level, the reference to wild goats is equivocal because the accounts available in English are translations of eighteenth-century Spanish. This problem is illustrated by the mention of buffalo. The translator notes that the Spanish word "cibolos," translated as buffalo, was being applied to elk by the explorers, who had not seen this animal before and had no Spanish name for it (Wagner 1933:162). Blee (1989) has described the confusion that resulted when Russian settlers at Sitka, Alaska, used the word "iaman" (often translated as "wild goat" or "wild sheep") for the small Sitka black-tailed deer. Dall sheep (*Ovis dallii*) are not found on Baranoff Island where Sitka is located, and the mountain goat was introduced in 1923. Nevertheless, there were repeated references to "iaman" in nineteenth-century Russian-language documents. Archaeologists found no goat or sheep bones at nineteenth-century sites, but they did find faunal material from the Sitka deer. Therefore, Russian speakers at Sitka must have applied their word "iaman" to refer to a goat-sized deer. Blee notes

> It was not unusual for Old World emigrants to name unfamiliar North American fauna for similar animals in their homeland. English-language examples abound: the American wapiti was called an "elk". ...The animal that Americans have named a "moose" is referred to as an "elk" in Europe. The American bison was likewise called a "buffalo" and the pronghorn an "antelope" in popular literature. ...Notably, the American mountain goat is not a goat at all, but is rather a type of antelope (Blee 1989:229).

Blee recommends a multidisciplinary and broader contextual approach when "deciphering the identity of animals described in literature dating to past centuries and written in languages other than English" (Blee 1989:230).

Moreover, the difficulty of identifying animal species mentioned in early accounts is not limited to the problems of translation between languages and European transpositions; English common or colloquial names were applied very casually and inconsistently through the nineteenth century. Again, the mountain goat serves as a good example of this situation. According to Burroughs (1961), Alexander Mackenzie apparently referred to mountain goats in 1789 as "white buffalo." Lewis and Clark used the term "goat" throughout their diaries to refer to the pronghorn (*Antilocapra americana*). They also consistently referred to mountain goats as "sheep," which led initially to the animal being misclassified by scientists into the sheep genus *Ovis*.

Another unconvincing aspect of the early Spanish references to the presence of goats along the Strait of Juan de Fuca is their very general nature. It is not apparent that they are based on any specific sighting at a given time and place. They are rather a passive assertion that "goats are found there." In contrast are the very detailed descriptions given by Eliza and Pantoja of the elk that was shot at Discovery Bay. It is very certain that the Spaniards were describing an elk. There is no such authentic, firsthand, descriptive account of a mountain goat. In fact, there were wild goats in some of the areas the Spaniards explored; they found a carved plank depicting goats along the coast of British Columbia. They also observed the widespread use of both goat and dog wool by Native Americans along the Strait of Juan de Fuca and did not always distinguish the difference. However, it is not probable that they saw goats along the southern coast of the strait.

In the summer following Eliza's exploration, Vancouver distinguished between the Puget Sound Indians' use of dog wool and another type of finer wool, but he could not find the animal that provided that wool in the Puget Sound area and did not learn what it was until a year later when he saw mountain goat skins near Bella Bella, British Columbia. Wool obtained from mountain goats in the Coast Range and the Cascades was widely traded along the coast of British Columbia, on Vancouver Island, and throughout the Puget Sound area (Schalk 1993). Most likely it was the widespread use of goat wool among Olympic Peninsula tribes that led some nineteenth-century explorers and writers to assume that mountain goats were present in the Olympic Mountains.

Another problematic reference to goats on the Olympic Peninsula appears in C. A. Barnes's column in the 16 July 1890 Seattle *Press*, which contains the unelaborated sentence, "One goat was seen by the party" (Barnes 1890). Although journal accounts of their adventures by both Barnes and Christie were printed in full in the same issue of the *Press*, neither of these more detailed accounts mention the sighting of a goat. It should be noted that the accounts were most likely edited by Edmond S. Meany of the *Press*, chief organizer of the expedition, and Meany prepared some additional commentary (Majors 1981). These narratives do recount sighting, hunting, shooting, eating, and seeing the tracks of various other game animals—elk, deer, bear, wolf, wildcat, cougar, rabbit—and catching trout. The reference to the goat is another "passive" report—neither the goat, the date, nor the circumstances of the sighting are described. Neither is it specified that it is a mountain goat and not a domestic goat at large in the homesteaded portion of the Elwha Valley where the expedition spent several weeks. (Barnes's column also mentioned chicken.) It is unusual that the sighting of such a game animal in the Olympics would not have been noted in the explorers' daily journals at the time it occurred. It should also be added that none of the members of the Press Expedition were naturalists. They were ex-soldiers, Indian fighters, prospectors, and cowboys, with the exception of Harris B. Runnalls, a doctor who left the expedition before it entered the mountains. They made other errors in natural history—mistaking the drumming of ruffed grouse for the rumbling sound of nonexistent geysers, misidentifying Mount Carrie as Mount Olympus, and discovering a 4-foot thick ledge of silver-bearing ore, a mineral not since found in the Olympics (Wood 1967).

Samuel C. Gilman's mention of mountain goats in the Olympics is likewise a passive statement: "In addition to elk and bear...are deer, mountain goat, cougar, beaver, otter, fisher, wildcat, marmot..." (Gilman 1896:138). It is not related to any specific observation of the animal. A descriptive account of Gilman's and his father's trip into the mountains, as told to a Seattle reporter, gives no specific animal sightings other than the mention of shooting elk (Gilman 1890). Gilman was a civil engineer rather than a naturalist. His more general *National Geographic* article (1896) was submitted for publication only a few days before Gilman died at the age of 36 and may have been edited without his review.

Among the early expeditions, that of Lieutenant O'Neil in 1890 was the most thoroughly organized and systematically executed, involved the most personnel, and was the most comprehensive in scope, covering a broad portion of the eastern and southern Olympics. In addition, O'Neil had explored the northern range east of the Elwha River in 1885. Three naturalists accompanied the 1890 expedition. The detailed observations of Private Harry Fisher, not trained as a biologist himself, seem to reflect the influence of the naturalists Henderson and Bretherton in Fisher's use of scientific nomenclature and species identifications. Although some of the naturalists' accounts and field notes are available and O'Neil provided a lengthy descriptive summary of the expedition, it is Fisher's daily journal entries describing the terrain, plants, and animals that provide the most comprehensive information. Fisher and the naturalists surveyed the route the Gilmans explored the preceding fall and much additional territory. They spent much of 3 months in high country that offered excellent mountain goat habitat. Moreover, Fisher actively searched for wild goats and sheep with a telescope. He saw none (Fisher 1890).

Soon after the publicity surrounding the Press Expedition, and even before O'Neil's expedition had finished constructing its mule trails, prospectors and sportsmen began venturing into the Olympics. Considerable hunting activity occurred on the Olympic Peninsula during the latter part of the nineteenth and the early twentieth centuries. Elk were so heavily hunted that there were proposals in the early 1900's to create a national park on the Olympic Peninsula as an elk sanctuary, and elk preservation was a major impetus behind the creation of Mount Olympus National Monument in 1909. Bear, deer, cougar, and wolf were also hunted by settlers, prospectors, and loggers in addition to sportsmen. By 1930, the wolf had been hunted, trapped, and poisoned into extinction on the peninsula. However, the Olympic Peninsula was not noted in sportsmen's literature as a place to observe or hunt mountain goats before their introduction. Mountain goats are large, conspicuously white animals. Nineteenth-century observers reported that they could be seen "from a great distance feeding in large droves" where they were present (Suckley and Gibbs 1860:137). Yet numerous accounts of recreational excursions that usually mention the major game animals found in the Olympics do not mention mountain goats. Such accounts do, however, occasionally mention encountering cougars, a much less conspicuous and more reclusive animal.

The wildlife observations of longtime local residents who spent much of their adult lives hiking (and building) the trails of the Olympic Mountains provide especially credible information. Some of these local observers were professional hunters, trappers, and outfitters who made a living by their knowledge of where to find wildlife. Grant Humes was one such person. A large collection of Humes family letters covering more than 35 years contains no mention of mountain goats, although these letters represent only scattered observations, and not a comprehensive treatise (Grant W. Humes, Olympic National Park library, unpublished letters, 1897–1934). However, E. B. Webster of Port Angeles, a publisher, outdoorsman, conservationist, amateur botanist, and observer of wildlife, was acquainted with Humes and several other Olympic Peninsula sportsmen, hikers, and state, county, and Forest Service wildlife managers. His book, *The King of the Olympics*, a collection of early observations about Olympic Peninsula wildlife, embodies much local knowledge of the native fauna. Webster's statement that mountain goats had never been present on the Olympic Peninsula probably represented the consensus of those local outdoorsmen who knew the peninsula best (Webster 1920:146).

The most credible early wildlife observations are probably those related by naturalists and biologists who had wide field experience, whose purpose was expressly to survey, describe, and collect the fauna, and who spent a considerable amount of time in those areas that provide goat habitat. Of particular interest is the catalogue of large and small mammals collected by biologists from the Field Museum in Chicago. The biologists spent 3 months on the Olympic Peninsula in 1898, and the catalogue made no mention of mountain goats (Elliot 1899). In addition, field reports of several members of the U.S. Biological Survey, covering the 1890's to 1921, fail to record the presence of mountain goats in the Olympics (USFWS circa 1860–1961). A group of these biologists, highly experienced in making wildlife observations and knowledgeable of where to look, spent more than 2 months in the Olympics in 1921, some of it in areas that could provide goat habitat. They would have searched not only for the animals themselves but also for their tracks, trails, wallows, droppings, and swatches of hair. Their reports listed not only the mammals that they observed or collected but also those about which they obtained reliable information from knowledgeable local residents. These investigators were comparing the various life zones of the Olympics with equivalent life zones in the Cascade Mountains, where mountain goats are present. Therefore, they would have been especially alert for any evidence of mountain goats. Dr. C. Hart Merriam, one of the preeminent American wildlife scientists and director of the U.S. Biological Survey, visited the peninsula in 1888 and 1897 and sought out information on animals from local hunters and trappers, game wardens, taxidermists, and museum curators as well as making his own field observations and being familiar with those of his colleagues. He concluded that mountain goats were not found on the Olympic Peninsula (Merriam 1897). (Merriam was aware of S. C. Gilman's *National Geographic* article which stated the contrary; a copy of it is located with his papers in the Library of Congress.)

Lyman has argued that "mountain goats might not have been recorded because appropriate areas were not surveyed" (1988:14). However, there was considerably more early exploration than Lyman reports. Lyman does not consider the 1885 and 1890 O'Neil expeditions nor the Press Expedition. Both O'Neil expeditions—but especially that of 1890—covered large areas that presently constitute mountain goat range. The Field Museum expedition in 1898 spent several weeks at elevations above 1,200 m in the vicinity of Boulder Lake and Mount Appleton, an area where mountain goats are currently found. The 1921 Biological Survey team visited the high meadows on Hurricane Ridge and the headwaters of the Dosewallips River, areas that support introduced mountain goats. E. B. Webster made more than 200 trips to timberline, many of them more than a week in duration. Forest ranger Chris Morgenroth was familiar with every trail across the Olympics and with remote areas that had no trails; so was Elwha Valley pioneer Grant Humes. Each of the latter outdoorsmen would have been familiar with almost every conceivable area of the Olympic Mountains during the 25 years preceding 1925. Not only did these men leave written accounts of their observations, but Biological Survey members interviewed them. None of these expeditions or knowledgeable sources reported finding mountain goats or any evidence of their presence. From the thoroughness of the wildlife observations they did report, it is reasonable to assume that if these experienced observers had indeed known of mountain goats in the Olympics, they would have reported them.

Anunsen (1993) has cited three sources to support the contention that mountain goats are native to the Olympic Mountains: Gilman's 1896 *National Geographic* article, the 1890 Seattle *Press* article, and John Dunn's 1844 comment that the Indians at Cape Flattery wove blankets of goat wool. Schalk (1993) has demonstrated that the historic use of goat wool does not prove the presence of mountain goats on the Olympic Peninsula. The other two references to the presence of goats in the Olympic Mountains are unsupported by any observational detail. Neither account provides any information on the circumstances, location, or date of a specific goat sighting, nor a description of the animal. When weighed against the numerous, detailed observations provided by skilled wildlife observers who did not find evidence of goats during this same period, such reports are clearly of questionable validity. Establishing the composition of the historic fauna of the Olympic Mountains has required consideration of many accounts from various sources and careful evaluation of their reliability. I found no convincing evidence that mountain goats actually occurred on the Olympic Peninsula before their introduction in 1925.

Appendix C. Mountain Goat Capture

R. W. Olson

Methods used to capture/remove mountain goats (*Oreamnos americanus*) and criteria used to evaluate the techniques are described in this appendix (see Table 36).

Method

Rope snare: A noose of braided rope was placed on the ground in a location where animals congregated or were attracted by salt or urine. The technique required animals that were habituated to humans and was most effective in late spring–early summer when goats craved salts. Capture sites were chosen to minimize damage to the surrounding vegetation, the capture team, and the goats. The goat, snared by a leg, was physically restrained by the capture team. Capture of mature males was difficult and dangerous. The technique was used extensively during research projects where animals were captured and released on-site.

Other traps/snares: Padded leg-hold traps and cable bear snares were tried unsuccessfully on Klahhane Ridge. Clover-type live traps were considered but not used.

Chemical immobilization: Goats were captured with M99 (Etorphine) and various M99 admixtures early in the program; Carfentanil citrate was used for later immobilizations.

Combined tactics: During unsuccessful or prolonged drug induction, capture was sometimes completed by net-gunning.

Evaluation Criteria

Precapture Requirements

The level of effort or planning required before using the technique included reconnaissance, site preparation, equipment preparation, baiting, and more. Drop nets and drive nets, in particular, required considerable logistical support from helicopters to position the heavy, bulky capture equipment. Both also entailed the use and transport of large numbers of personnel.

Population Requirements

Passive techniques, in particular, were most successful when used on high-density subpopulations that had become habituated to humans.

Selectivity

How effectively could a specific animal (i.e., sex or age class) be captured? This was of concern when conducting capture/translocation programs because the receiving agency often specified preferences.

Multiple Capture

What was the potential to capture more than one animal at a time with the technique? Was it feasible to capture intact social groups, such as females with kids?

Safety to Personnel

How hazardous was the technique to personnel? Our assessment assumed the use of experienced, trained people familiar with mountain goat capture and restraint techniques and experienced in helicopter operations in mountainous terrain.

Safety to Mountain Goats

How hazardous was the technique to the animal? The net gun and drive net required physical entanglement to subdue the goat. This sometimes led to dangerous situations over which the capture team had little or no control.

Cost per Animal

The estimates in Table 36 are in 1992 dollars but are based on the 1981–89 capture efforts.

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ERRATA – MOUNTAIN GOATS IN OLYMPIC NATIONAL PARK -- 23 Feb. 1995

Please make the following corrections to the volume:

p. 39, Fig. 14. Caption: "The maximum proposed extent of Laurentide and Cordilleran ice sheets ~~at approximately 10,000 B.P~~..."(delete last phrase).

p. 48, l. 26. (Scheffer 1949) citation omitted from text. Scheffer, V. B. 1949. Mammals of the Olympic Peninsula, Washington. Unpubl. mss. U.S. Fish and Wildlife Service. (Also cited on p. 260, 285, and 287).

p. 99, Table 21. Subheading **Elk**, lines 11 and 14, "Unknown" categories, right justify both rows. Under subhead **Deer**, line 18, "~~Miscellaneous...4... 11... 5~~" (delete the entire row).

p. 187-231. Running head is incorrect. Series number is 25.

p. 278, l. 9. (Hanna 1907) reference omitted from Lit. Cited: Hanna, I.M. 1907. Expedition into the Olympic Mountains. Mountaineer 1:29-34.

p. 280, l. 15, 285, l. 2. (Morgenroth 1908) citation omitted from text. Morgenroth, C. 1908. Report on Olympic National Forest. Unpubl. mss. Historical files, Olympic National Forest, Olympia, Washington.

p. 281, l. 3. Merrill (1880) reference omitted from Lit. Cited: Merrill, J.C. 1880. On the habits of the Rocky Mountain goat. Report of the U.S. National Museum for 1879. Washington D.C. p. 283-284.

p. 284, l. 32. (Schullery 1984) reference omitted from Lit. Cited. Schullery, P. 1984. A history of native elk in Mount Rainier National Park. Final report to the National Park Service, Mount Rainier National Park, Washington. 110 pp.

p. 286, l. 25. Citation omitted from text: Washington State Game Commission 1940. Fourth Biennial Report, Olympia, Washington.

As the nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering sound use of our land and water resources; protecting our fish, wildlife, and biological diversity; preserving the environmental and cultural values of our national parks and historical places; and providing for the enjoyment of life through outdoor recreation. The department assesses our energy and mineral resources and works to ensure that their development is in the best interests of all our people by encouraging stewardship and citizen participation in their care. The department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

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